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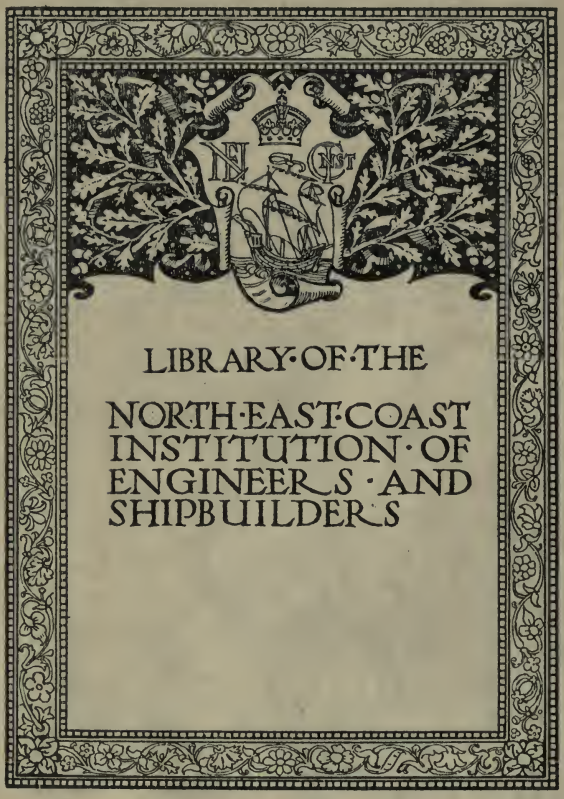
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PRACTICAL
SHIPBUILDING

A TREATISE

ON

THE STRUCTURAL DESIGN AND BUILDING OF MODERN STEEL VESSELS

THE WORK OF CONSTRUCTION, FROM THE MAKING OF THE RAW MATERIAL TO THE EQUIPPED VESSEL, INCLUDING SUBSEQUENT UP-KEEP AND REPAIRS.

BY

A. CAMPBELL HOLMS

MEMBER OF THE INSTITUTION OF NAVAL ARCHITECTS AND OF THE INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND
SURVEYOR TO LLOYD'S REGISTER OF SHIPPING

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LIFE MEMBER S.N.A.M.E #01702900

IN TWO VOLUMES

VOLUME I. TEXT

LONGMANS, GREEN, AND CO.
39 PATERNOSTER ROW, LONDON
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PREFACE

In submitting this work to the public, I do so with the hope that it will find the sphere of usefulness, the contemplation of which has been my sole impulse in writing it. I believe it will be found useful in many quarters, if only from the circumstance that there is no other published work dealing in an exhaustive way with the practical questions and operations of modern shipbuilding. I have attempted to supply this want, so that those who desire to obtain full information may do so readily by a mere perusal of these pages. In the absence of books, the only way to obtain trustworthy knowledge of the various procedures adopted in the designing and construction of ships, and of the reasons governing them, is by close personal observation and reflection, a method which, of course, requires much time and a great deal of patience.

I have endeavoured throughout the book to avoid all abstruse questions of theory, and to make the explanations so clear that they may be easily understood by all intelligent readers, whatever their previous training. Books on the theoretical questions of naval architecture are numerous, so that those who wish to obtain accurate and full knowledge of this kind may readily do so. While avoiding anything of an abstruse nature, I have described in a popular way those fundamental matters of theory which govern the structural design, and without which an intelligent appreciation of the subject would be impossible. I have extracted much information of a standard character from the technical papers published by the various engineering and shipbuilding societies, and where any matter is of such special interest as to merit a closer study, reference is made to different sources which will supply it.

The plan of the book is briefly as follows: Firstly, attention is given to the fundamental matters which govern the structural design; the various stresses to which the hull is exposed, their straining tendency, and the different structural designs by which the necessary strength to resist them may be secured. Secondly, each important part of the hull is considered by itself, and each one from three points of view, viz. its purpose in the structure and the particular stresses and straining effects to which it is liable; the various formations adopted in its design, with the rules governing them as regards scantlings and strength; and a description of the actual work of making it in the shipyard and fitting it in the ship. As a description of the actual work of the shipyard is reading of a special character, it is dealt with separately in the second part of the book, the

sequence, generally, being thus better preserved. As Lloyd's rules represent and govern, it may be said, all merchant shipbuilding practice, they are frequently referred to and explained, the numerous sketches in the book of plates being practically all drawn in conformity therewith.

There will be found chapters on corrosion, launching, etc., and on the work of the drawing office—that most important department—where, previous to the actual building work, the qualities of the ship are decided upon, and every part designed and measured on paper. The manufacture and mechanical qualities of mild steel are also dealt with at some length, a proper knowledge of this being an important matter to those whose duty it is to deal with the material in the shipyard. Finally, I may say that every important matter affecting ship construction has received more or less detailed attention.

As I have aimed at making the book useful for purposes of reference as well as for systematic or general study, I have added a very complete alphabetical index; and to facilitate the complete study of any particular subject, I have referred, when dealing with it anywhere in the text, to other parts of the book where it may be noticed in some other connection. At the beginning of the book there will be found a list of the chapters, giving in outline the subject-matter dealt with in each.

The writing of this work, and the preparation of the numerous sketches, have occupied all my leisure time for some years, and as the art of shipbuilding has of late made many advances, the necessity of presenting the book in a thoroughly up-to-date state has greatly delayed its publication.

A. CAMPBELL HOLMS.

March, 1904.

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PART I.

PRACTICAL SHIPBUILDING

CHAPTER I

Art. 1. Until about 1840 practically all vessels were of wood. By that time great perfection had been attained in the use of this material, but its possibilities in the matter of size were limited, for, although in some exceptional cases a length of 300 feet was attained, few wood ships exceeded 200 feet. Even when of this moderate size, to make wood sea-going ships quite strong enough is impracticable, for, as the numerous short pieces of which they are composed can be but imperfectly connected, the inevitable slipping or straining movement of each one upon its neighbour results, in time, in a large and permanent deformation of the hull, so much so that in old vessels the keel line often departs some feet from the straight, bending upwards in the middle, or "hogging," as it is termed. Although many of those accustomed to wood scouted the idea of iron sea-going vessels, they had soon to admit their superiority. It was forcibly demonstrated by the accidental stoppage of some of the early vessels during the launch, which involved their taking, at low tide, a bridge-like position, supported at either end, or with a large portion overhanging; and, although subjected to such abnormal stress, the hull showed little or no sign of bending. No wood ship could have withstood such treatment; when lying afloat immediately after launching, they were often found to have bent some inches from the straight. The precise date at which iron was first used for shipbuilding is unknown, for, to begin with, it was employed in a tentative fashion for canal barges and the like.

Art. 2. The principal feature of the hull is the **shell plating.** If the upper deck be regarded as a horizontal portion thereof, then all other structural parts are more or less subsidiary, their purpose being to stiffen and support it. In small boats the shell plating alone may suffice; excellent lifeboats are made whose essential structure is two sheets of thin steel, one for each side, pressed to the desired form and united to a continuous bar, forming the keel, stem, and sternpost. In a large vessel the shell is composed of numerous plates, riveted together; and although alone it might fulfil the fundamental condition of impenetrability to water, so elementary a structure would, of course, lack many other essential qualities. The hull of a sea-going vessel must have strength and rigidity, such that when deeply immersed by heavy masses of cargo it will suffer no deformation or excessive stress. The deforming forces may be very severe; in a large vessel the fluid pressure tending to collapse the sides or force up the bottom may amount to many thousands of tons; and, together with this ever-present straining tendency, the structure must withstand the enormous accentuation of stress caused by violent blows from stormy seas, pitching and rolling

from side to side, and lying bridge-like across the waves. Though subjected to these forces, there must be perfect immunity from straining; there should be no perceptible bending either in the hull as a whole or in its component parts, for if there were the numerous riveted joints might soon become loose, admit water, and finally give way. Also, in a steamer, if the machinery, with its shafting, etc., were bolted to a hull not perfectly rigid, it could not run with the unfailing precision so essential to the safe performance of long voyages.

The thin shell plating requires to be stiffened by interior **framework**, disposed both transversely and longitudinally; and, further, the two sides, thus stiffened, must be united by cross beams to hold them at fixed distance and support them against collapse. Theoretically considered, while maintaining the same general strength, the arrangement of the framework might be greatly varied; the same total strengthening effect could be given by *ribs*, or *frames*, of massive character but few in number, *i.e.* placed at wide intervals; or by numerous slender ones placed closer together. If the latter system were carried to excess, the ultimate result would evidently be equivalent to a mere thickening of the shell plating. If sufficiently thick, the shell might, indeed, become self-supporting, but, of course, so great a thickness would be required as to render the vessel useless as a cargo carrier. Similarly, if the frames were very widely disposed and proportionately massive, although they would preserve the form of the hull as a whole, they would not give sufficient local stiffness to the plating; in order that this might not yield between them, it would still require to be excessively thick.

Art. 3. The **most efficient cargo vessel** is that which—other qualities secured—can carry the greatest weight or bulk of cargo in proportion to her size and first cost. Small size or tonnage is advantageous, for it means that the rateable value upon which the dues—a constant source of expenditure—are charged is small; if bulky, light cargoes are carried, however, the vessel's size or tonnage also measures her carrying capacity, so that to be small is here no advantage. A light hull, involving a small weight of structural material, is advantageous, because it not only reduces the first cost in the matter of material, but increases ever afterwards the vessel's weight-carrying or earning power; for, of course, every ton of weight saved in the hull permits of the conveyance of one ton more of cargo. When competition is keen and freights may be just sufficient to pay interest on the capital outlay, a small first cost is evidently essential to commercial efficiency.

Cost of construction is made up of two items—**material** and **workmanship**. The latter is the more important; it is dependent to a certain extent on the quantity of material used, but to a greater on simplicity of construction, *i.e.* whether the parts are few or numerous, whether of simple or complicated form, and whether easily and expeditiously combined or otherwise. The cheapest structure is the one involving a minimum of structural material and of skilled labour. With a given strength these two conditions are opposed, if the one is great the other is small; a vessel built of few parts, which make up in massiveness what they lack in number or efficiency of form and disposition (as in the imaginary case of a hull composed of a thick shell only), would involve less skilled labour than one having numerous parts, slender, but efficiently formed and disposed for their more specialized duties. Such a vessel, however, would be costly in raw material and inferior as a cargo carrier. So important are carrying capabilities that it is always desirable to reduce the weight of the hull, even though the first cost be slightly increased by the greater number and

complexity of parts. But there is a limit to the application of this principle, for although, theoretically, the necessary strength might be maintained with very slender parts, the resulting structure would have little endurance; it would be unable to withstand the effect of wear and tear; the wasting tendency of corrosion and the bumps and blows of active service would cause such rapid deterioration as soon to involve costly repairs and shorten the vessel's period of useful existence. In warships, where wear and tear are almost negligible factors, a very slender structure is admissible. In these vessels a light hull is essential, and is secured—often at high cost in workmanship—by slender parts, disposed and associated in the most efficient manner.

Art. 4. Notice, in a general way, the arrangement of the main framework of the hull (see Plate 100). The **transverse frames** form continuous ribs round the body of the ship; they give to the thin and yielding shell plating the necessary lateral stiffness, and resist all stresses tending to alter the form of the transverse sections. Alone, however, they would give but imperfect rigidity; if conjoined only through the medium of the shell plating, each one would practically be independent of those adjoining, and so would only resist those stresses which directly affected it. In order, therefore, that they may give a combined, and, consequently, a powerful resistance, they are united by **longitudinal frames**—the keelsons and side stringers. These bind them rigidly together, so that no frame may strain or yield independently of those adjoining, adjacent ones simultaneously resisting any forces tending to deflect the sides or bottom.

A vessel's framework is thus composed of two sets of frames; the transverse and longitudinal. The former are always disposed in direct contact with the shell, at intervals of about two feet. They constitute the main skeleton of the hull, the shell plating and other parts being fitted to it as a groundwork. The latter (termed *keelsons* when on the bottom, and *side* or *hold stringers* when on the side) are fitted in continuous lengths within the transverse. They are wider apart, and form, as it were, a supplementary skeleton. In large vessels, or where superior strength is required, they are connected not merely to the inner surface of the transverse frames, but extend, *intercostally*, between them, so as to connect to the shell (see Plate 101). The lower part of each transverse frame, lying across the ship's bottom, is made exceedingly strong compared with that on the side, for the bottom must sustain the weight of heavy cargo, and is liable to severe pressures through grounding or resting on the keel in dry dock; while elsewhere they are mere bars, here they are formed of deep plates, termed *floors*. For a similar reason the longitudinal frames of this part are made stronger than those on the sides. The one directly over the keel—the *centre keelson* or *vertical keel*—is exceptionally massive. It might be regarded as the backbone of the vessel's bottom.

Art. 5. A ship is appropriately likened to a **large floating beam or girder**, for both undergo bending stresses [1] of a similar nature, and, in a ship, the structural material is to a large extent distributed agreeably with the principles governing girder design. Also, every structural part of the hull is introduced with a view to resisting certain stresses more or less definite, and as these all tend to bend the part, each, when its capabilities are investigated, may be regarded as a beam or girder. Accordingly, to

[1] Throughout this work the term *stress* will be used in the now accepted sense to denote any force acting upon, and tending to deform, a body, as also the corresponding internal force of resistance which the body opposes to such deformation. The term *strain*, to signify the deformation induced by the external stress or force; or, in a compound structure, the relative slipping movement that may occur betwixt its component parts.

appreciate intelligently the manner in which a ship's hull, in whole or in part, resists deformation, and the arrangement of the various parts best suited to their special duties, it is evident that a knowledge of the laws governing a simple beam or girder is indispensable. In order, therefore, that readers unfamiliar with these matters may grasp the necessary principles, the subject is treated in an elementary fashion in the Appendix.

To understand the particular purpose, or usefulness, of the various component parts of the hull, a knowledge of the **straining forces** to which vessels are exposed, and which, therefore, must be provided against, is essential. These forces may be divided into two broad classes, **longitudinal** and **transverse**. The former tend to produce longitudinal deformation bending the hull as a whole; the latter, to distort the form of the transverse sections. In the following chapter it is intended to notice, first, how longitudinal bending stresses may arise, and the circumstances which govern the intensity of their straining effect on the hull.[1]

[1] For interesting investigations on the subject of longitudinal bending stresses, reference may be made to the following, among other papers: Sir E. J. Reed's *Memoir to the Royal Society*, 1871. *Trans. Institution of Naval Architects:* Froude, 1874; Sir W. H. White, 1877; John, 1874–77; Smith, 1883; Read, 1890. *Trans. Institution of Engineers and Shipbuilders in Scotland:* Arnison, 1878–79; Biles, 1893–94. *Trans. North-East Coast Institution of Engineers and Shipbuilders:* Bergstrom and Piaud, 1888-89; Kendal, 1892–93.

CHAPTER II.

Art. 6. If a stranded vessel rested high and dry, each end upon a rock, as shown in Fig. 4, Plate 1, the hull, forming a bridge girder, would tend to *sag*, *i.e.* bend downwards in the middle. The fore-and-aft material at the upper part would suffer compressive stress, tending to crush it or make it buckle up; and that on the lower part, tensile stress, tending to stretch it or tear it across. In Fig. 2 the opposite conditions are depicted. Here the ship tends to *hog*, the stresses on the material being reversed. **Hogging and sagging stresses** are also experienced by every vessel when afloat among waves, and that they are identical with the above will be evident from Figs. 1 and 3, which depict a vessel floating amidst waves of exaggerated height. The upward supporting pressure, whether by rocks or the buoyancy of water, must equal the weight of the hull and contents; but in the latter case, owing to its better fore-and-aft distribution, the bending effect is, of course, much less intense.

Longitudinal bending stresses of a permanent or chronic character are also experienced by all vessels when floating **at rest in smooth water.** How brought about is forcibly illustrated by Figs. 8 to 10, Plate 1. In Fig. 8 the weight over each barrel causes neither hogging nor sagging stresses, for the buoyant effect of the latter is equal to, and lies exactly under, each weight. In Fig. 9 sagging stresses prevail, for while the buoyant effect acts at the ends of the plank, the load acts at the middle; and, conversely, in Fig. 10 hogging stresses prevail. In a ship precisely similar conditions may be experienced, much less in degree, however; for although the displacement varies throughout the length, it does so gradually, every part of the hull and cargo receiving some support—not necessarily a balancing one—directly from below. If, for instance, only one hold amidships were filled with heavy cargo, and all the others were empty, it is clear that the weight of the loaded compartment would not be balanced by its displacement; it would have to be borne in great part by upward forces of buoyancy acting elsewhere, towards the vessel's ends, and, consequently, the hull would tend to sag, just as if it bridged the trough of a wave. Similarly, if the end compartments were heavier than their displacements, the excess of weight would be borne by the surplus buoyancy of the midship part, and hogging stresses would prevail.

The severity of **hogging and sagging tendencies,** and their straining effect on the hull, depend on the length and height of the waves encountered, the vessel's dimensions, and her condition as to loading. They are most intense when the waves are high and have a length, from crest to crest, equal to that of the ship itself; and they are greater in long, shallow vessels than in shorter, deeper ones. As just seen, the weight and distribution of the cargo have a commanding influence; heavy weights towards the bow and stern, or absence of weight amidships, intensify hogging stresses; and an excess of weight amidships accentuates those of a sagging nature,

According to the loading, some parts of the hull may suffer sagging stresses and others hogging ones. In all vessels the extreme ends are heavier than the local displacement; here, therefore, there is a permanent hogging tendency. When loaded uniformly with homogeneous cargo, the weight and corresponding displacement in way of each cargo hold are usually fairly well balanced. In the region of the machinery, however, the hull and contents—the engines, boilers, and coal—usually represent a lesser weight than the local load displacement, the difference becoming more marked towards the end of a voyage, when the coals are consumed from the bunkers. And, on the other hand, when the vessel is in light trim, the weight of the machinery section is heavier than the local displacement. In light, high-powered, channel steamers the concentrated weight of machinery amidships, and the unloaded, buoyant ends, may result in severe sagging stresses; those of a hogging nature, contrary to what is usual, being less important. If the cargo is not uniformly distributed, but is composed of heavy, isolated weights, the resulting stresses on the hull may be exceptionally severe; if exceedingly localized, the tendency may be not so much to bend the hull fore and aft as to shear it in two, transversely. If, for instance, empty and heavily laden holds occurred alternately, the bottom of the hull, in way of the former, being subject to an upward sea pressure entirely unbalanced from within, would tend to move upwards, from bulkhead to bulkhead; and contrariwise in way of the latter. These tendencies, moreover, would be accentuated and reduced as the water pressure in way of each hold was increased or diminished by variations in the draught due to passing waves, or as the weight carried was virtually increased by vertical movements of the vessel.

Art. 7. If, when subjected to **hogging or sagging stresses,** the position of the supporting pressures and the weight of the hull are known, it is a comparatively simple matter **to compute the bending moment** and the intensity of the resulting stresses, tensile and compressive, which the structural material will suffer. At an early period of iron shipbuilding such investigations were made, but, to simplify the calculation, the hull was assumed to occupy a high and dry position, poised upon a rock amidship or on one at either end, as in Figs. 2 and 4, Plate 1. Of course, no vessel could withstand so severe an ordeal; even if strong enough to resist the resulting bending tendency, the hull would be crushed and penetrated by the intense local pressure of the rocks. Vessels are often accidentally stranded on a bank, but as they are usually fairly well water borne, the effect of inequalities in the support is minimized. To attempt to provide them with sufficient strength to withstand the bending stresses incurred by so remote a contingency as a girder-like position, high and dry between supports, would evidently be quite inexpedient, for the hull would be so heavy as to have little efficiency for its legitimate work.

When **afloat in still water,** it is a simple, though laborious, matter **to calculate** with precision, for any condition of loading, the bending moments and corresponding **stresses which the material** of the hull **will suffer;** and, unless the loading be very abnormal, these chronic stresses are usually of minor importance. Such calculations, however, are of little practical value, for they give minimum stresses, whereas what it is desired to know is the most severe stress the structure is likely to suffer, when heavily laden and while rising and falling amidst high waves. Investigations towards this end are frequently made; but while very instructive, as indicating how the severity of the stresses may be affected by differences in dimensions and conditions of loading, they are unreliable as giving, quantitively, the actual stresses suffered by, or the strength required in, any

particular ship; for not only are important conditions as to length and height of wave arbitrarily chosen, but many complex matters regarding wave structure and vertical movements of the hull, not susceptible of mathematical treatment and which greatly influence the results, are of necessity neglected. If the most severe bending moment that a ship would suffer in actual service were known, it would be a simple matter so to design the structure of the hull that it would have the precise strength compatible with any chosen margin of safety. Treating the vessel as a girder, poised, high and dry between supports, then, if the hull were prismatic and uniformly loaded, the bending moment amidships, in foot-tons, would be one-eighth of the vessel's weight multiplied by her length. Numerous calculations indicate that in the case of a loaded ship, afloat amid waves of the largest size likely to be encountered, the maximum bending moment will rarely exceed one-thirtieth of her weight multiplied by her length. Taking this as a basis, it is found that in most well-constructed ships the strength of the hull is sufficient to leave a fair margin of safety under all but very abnormal conditions, a tensile strength of seven tons per square inch of the steel being seldom attained.

It may be noticed here that the **longitudinal bending** effect of hogging and sagging stresses is little more than a tendency; for though the tensile and compressive stresses set up in the structural material may approach the elastic limit of the steel, the hull is so deep and rigid that the resulting **deflection from the straight** is very small, probably not more than a few inches even in a long vessel.[1]

In the investigation above referred to, the vessel is commonly assumed to be loaded with homogeneous cargo, and to be poised on the crest of a wave of her own length, and in height one-twentieth of her length. When so circumstanced, the bending stress is a hogging one; and it is usually more severe than the corresponding sagging stress, chiefly owing to the fact that after a long voyage, when the 'midship coal bunkers are empty, the hull is disproportionately heavy towards the ends, just where it receives the least support. In making the calculation,[2] an outline of the wave is drawn, in such a position with regard to the hull that the irregular volume which it cuts off is equal to the displacement in still water. The forces of buoyancy and the opposed weight of each small, contiguous, transverse section of the hull are then computed, and their differences being obtained, the bending moment at any part can at once be ascertained. It is then a comparatively simple, though laborious, matter to ascertain, by treating the ship as a girder, the tensile or compressive stresses that the structural material will suffer at any particular part.

Art. 8. But the assumption that a vessel displaces the same volume of water on the crest or hollow of a wave as in still water is not correct. The **buoyant effect** of the water forming the **upper part of a wave** is less than that of still water, and, accordingly, to obtain an equal support, the hull must sink deeper; and, conversely, the water in the **lower part** is more buoyant, so that a lesser immersion is required for the same effect. Refined investigations,[3] in which this is taken account of, show that the

[1] An account of some practical experiments in this direction will be found in Mr. Phillips' paper, *Trans. Institution of Naval Architects*, 1891; and a theoretical consideration of the subject will be found in a paper by Mr. Stanbury and the late Mr. Read, *Trans. Institution of Naval Architects*, 1894.

[2] The actual work of these calculations is well described in Sir W. H. White's and Mr. Thearle's works on naval architecture, as also in some of the papers already cited, notably that of the late Mr. John, *Trans. Institution of Naval Architects*, 1877, and of Prof. Biles, *Trans. Institution of Engineers and Shipbuilders in Scotland*, 1893-94.

[3] See Mr. Smith's paper, *Trans. Institution of Naval Architects*, 1883.

actual sagging moment may only be about one-half that found by cruder calculations, and, while hogging stresses are also found to be less, the difference in their case is only about half as great. These very large discrepancies explain satisfactorily how it is that vessels, which by ordinary calculations would appear to be liable to a stress on the upper works exceeding ten tons per square inch, so rarely show signs of it by serious straining.

It may be readily shown how the water of a wave-crest and that of the hollow have respectively a smaller and a greater buoyant effect than still water. The buoyant effect of a fluid depends on its weight; salt water is more buoyant than fresh, because it is heavier; mercury is so heavy that lead floats in it. A bucket of water, when shot into the air, has virtually no weight; during the flight a piece of iron or cork—also virtually without weight—will remain wherever it may happen to be, at or below the surface. In the same way, a man jumping over a fence with a weight on his back will feel no pressure, or weight, while in the air. If a mass of anything, attached to a cord, be swung round in a vertical circle, its weight when at the bottom of the swing, as evidenced by the pull on the cord, may be very much greater than the actual, while at the top it may appear to have no weight at all. Now, in accordance with the *trochoidal* wave theory—now accepted as the correct one—every particle of water in a wave moves in a vertical circle, and so, as in the case of the cord and weight, the particles forming the upper half, or crest, suffer a virtual reduction of weight, and those of the bottom an increase. The orbital motion is slow, so that the loss and increase in weight is not so great as in the suggested case of the cord and weight or the bucket of water moving freely under the force of gravity, but it is sufficient to affect appreciably its power of supporting a vessel's hull; to receive the required support, this must sink more deeply in the crest and less deeply in the hollow. It follows, therefore, that when a vessel lies across a wave-crest, the support given at the deeply immersed 'midship part and that at the little immersed ends are rendered less unequal, and, consequently, the bending effect on the hull is less intense; and similarly when astride the wave hollow.

Apart from its effect on the buoyancy of wave-water, the circumstance that **a mass, oscillating in a vertical path, virtually loses and gains in weight,** may have a commanding effect on the longitudinal bending stresses suffered by a ship when moving up and down amidst waves. As the hull rises to the upper part of the wave and then begins to descend, it is virtually lighter, and, in consequence, suffers less bending stress; and, similarly, when it descends into the trough and begins to ascend it is heavier, and suffers more. This phenomenon will be familiar to any one who has been at sea in rough weather. Standing towards the end of the vessel, one may be almost lifted off the deck at the top of an upward heave, and at the bottom feel one's self abnormally ponderous. Similarly, everything on board, and the vessel itself, is subject to a like effect. Small sailing-boats heel over and more readily capsize when on a wave-crest, their virtual lightness having the effect of a loss of ballast. In the case of a large vessel floating amid waves, the **up and down movement of the hull,** as a whole, is, of course, slow and steady; she does not rise to the waves like a raft. It may happen, however, should a suitable series of high waves be encountered, that, although not rising much to the first, she may do so more and more as each succeeding one gives her an additional impulse—just as a weight suspended by a piece of elastic, if subjected to small but suitably timed pushes, will oscillate through gradually increasing distances. The effect of such movement on the bending stresses

suffered by a ship has been investigated,[1] and with surprising results, for it was shown that the vertical movement of a large vessel might, after accumulated impulses, become so great that, at the top of a vertical oscillation, *i.e.* on the crest of a wave, the hull would rise (be shot up, as it were) some nine feet above the normal. Similarly, in the wave-hollow, the hull, being virtually heavier, might sink by a like amount below the normal, as indicated by her displacement below the wave surface. It was found that, as a result of such movement, the hogging stresses in a fine-lined vessel might be reduced by some 8 per cent., but that the sagging stresses might be increased by as much as 24 per cent. It is fortunate that the increase is in the less severe sagging stresses and not in the more critical hogging ones.

The above investigation also shows that, although in a **fine-lined ship** the increase in sagging stresses might be as much as 24 per cent., in **one of fuller form** it might be only half as much. That this may be so will be evident from the fact that if a ship were so full as to be prismatic throughout, she would not move at all, vertically, as a whole, for the wave profile (the wave being of her own length) would cut off an equal volume of displacement, no matter where the crest were. If, on the other hand, the ends of a ship were conceived to be so exceedingly fine that all the displacement were concentrated amidships, the hull would rise like a raft to the full height of each wave. In the former case, there being no vertical movement, there would be no virtual variation in weight, and so no increase or diminution in bending stress. It has long been a disputed point whether or not a fine vessel, carrying little cargo towards the ends, and, therefore, subject to comparatively small bending stresses, should be built of lighter scantlings than a fuller and more heavily laden one. In practice, however, it has often been observed that, when straining tendencies do occur, they do so about as readily in the one type as in the other, and so the usual practice is not to modify the general scantlings on account of variations in fulness towards the ends. This receives considerable support from the foregoing circumstance, namely, that, owing to their greater vertical movement in a sea-way, fine-lined vessels may suffer a greater accentuation of sagging stress.

The **molecular movement of wave-water** may have a further effect in inducing or **modifying longitudinal bending stresses.** The water forming the upper half, or crest, of a wave moves forward, whereas that in the trough moves backwards; and so it follows that if a vessel lay obliquely across large waves, with her stem and stern in adjacent crests and the 'midship portion in the hollow, the opposed movements just referred to would tend to bend the hull sideways, as a whole, or twist it corkscrew fashion. The tendency itself is probably unimportant, but, when added to others simultaneously acting, the resultant stress may be considerably augmented.

It is evident from the foregoing that the **strength of structure** given to any particular ship is not a matter that can be **decided by** any precise theoretical treatment. In practice, the arrangement and massiveness of the various parts are simply that which long **experience** of the strength and endurance, displayed in active service by vessels of different sizes and type, indicates as the minimum compatible with these qualities. It may be remarked here that it is mainly due to *Lloyd's Register of British and Foreign Shipping* that this experience, extending over the whole history of iron shipbuilding, and which otherwise might have been lost, has at all times been carefully recorded, properly interpreted, and made available to all in the annual publication of their rules of construction and tables of scantlings

[1] Read, *Trans. Institution of Naval Architects*, 1890.

(Art. 40). Although practical experience is thus the ruling factor in deciding the most suitable structural design, this, nevertheless, is arranged in conformity with theoretical principles, which, when properly applied, are necessarily in agreement with practical experience.

Art. 9. It is now intended to notice, in a general way, the **structural design** of ships, large and small (see Plate 4), **in its relation to** the **longitudinal stresses** just considered. All vessels resemble, more or less, a large box-girder, *i.e.* one which is a hollow square in section—a design typical of strength and rigidity. In small vessels the longitudinal stresses are usually unimportant, and so in their structural design no special regard is given to girder principles; their upper flange, in their aspect as a box-girder, may only be partially represented by a marginal strip of deck plating, the *deck stringer* and the conjoined *sheer strake* (a wood deck is disregarded in questions of strength, Art. 17). In such vessels the strength and stiffness required to give a substantial hull, that will resist the wear and tear, bumps and blows, and local stresses of active service, amply satisfy those of longitudinal strength. As dimensions increase, however, so also do the longitudinal stresses, and in the arrangement and disposition of the structural material it becomes necessary to give special regard to girder principles. Greater strength is introduced where most required, *i.e.* by completing the upper flange, so that the deck, like the bottom, becomes a plated surface. The hull is then practically a tapered tube, a form well adapted to resist stresses of all kinds.

Art. 10. A girder of uniform section, when overloaded at the middle, fails at the part where the bending effect is greatest, *i.e.* at the centre of gravity of the load. The centre of gravity of a loaded ship is practically amidships, and so here the stresses are greatest; thence they gradually diminish, disappearing at the bow and stern. It follows that **the hull should be strongest amidships,** and in practice it is made so, for towards the ends it tapers in breadth, and the shell and all longitudinal parts are reduced in thickness. Further, when a vessel is just of a size to require additional strength, the extra structural material is mostly placed on the 'midship portion; thus, when deck plating is first called for, only the 'midship part is plated (see Plate 86); with increased dimensions, the entire deck is plated, and then a second and a third plated deck may be similarly introduced.

If the strength diminished from 'midships towards the ends in the same gradual fashion as the longitudinal bending moments, the hull would be equally tried throughout, *i.e.* it would be no more liable to strain at one point than another. The strength, however, does not decrease in this gradual way, and although, generally speaking, it is disproportionately great towards the ends, the weakest spot may, owing to **discontinuities in the fore-and-aft material,** be located some distance from 'midships. This may result from the presence of a deck erection; in way of a **'midship bridge-house,** for instance (Fig. 1, Plate 26), the hull is stronger, for it is deeper and is assisted by the longitudinal material of the bridge; but just at the ends of the latter there is an abrupt stoppage of longitudinal material and a sudden reduction in depth, and so, although the bending moment may be smaller here than amidships, the hull may nevertheless be more severely tried. But, further, the mere abruptness of the discontinuity may cause an intense concentration of stress, just as a nick in a stick is a ready source of fracture.

A tendency to strain at such points is constantly observed, particularly in large vessels and those which cross the stormy North Atlantic. **At the ends of the bridge** the rivets in the joints of the sheer strake

and bulwark plating may become loose, or, more rarely, the plates may fracture. In large vessels indications of straining are sometimes observed in the riveting of the gunwale bar, or in the rivets connecting the bulwark to the sheer strake, and those in the fore-and-aft seams of the bridge-side plating. The bulwark rail, being the highest part of the hull at this, its weakest section, is one of the first parts to indicate excessive stress, by fracturing or by straining of its rivet connections. Such localization of stress is provided against by doubling the sheer strake for about twenty feet across the weak spot—the ends of the bridge, poop, or quarter-deck (Fig. 13, Plate 15). Also, the bulwark plate which unites with the bridge side is made thicker, and is connected to the sheer strake by a double row of rivets; the bridge landings are double riveted at this part, and in large vessels the deck stringer plate may be doubled, and the end joints in this locality quadruple riveted instead of treble. Care should be observed not to increase the natural weakness of this spot by piercing the bulwark plate with large freeing ports; if it is, it should be locally doubled. It is common to find the bulwark plate cracked, the fracture originating at the sharp, square corners of the port. Also, if there is no bulwark, the lower strake of the bridge-side plating should extend for a few feet beyond the bridge, so as to avoid too sudden a discontinuity. It is well, also, that all such terminal plates should be tapered or curved, and the rail bar should be connected by a bracket to the bridge bulkhead (Figs. 13–15, Plate 15).

A **bridge-house** is usually regarded **as a mere superstructure** on the hull proper; not only is it of slender construction, but, in its structural design, continuity of fore-and-aft strength is not always studied; its side plating, for instance, may often be cut almost entirely away by large gangway doors (see Figs. 7 and 8, Plate 26). Now, not only may such a deck erection seriously affect, by its discontinuity, the strength of the hull, but, when it admits of the stowage of additional cargo, its presence may result in a considerable augmentation of the longitudinal bending forces. In such cases, therefore, it may be necessary to double the entire 'midship portion of the sheer strake (Fig. 7, Plate 26). In vessels of extreme proportions—long and shallow—the longitudinal bending tendency may be so severe that even a short 'midship superstructure may seriously augment them; accordingly, in such cases (when the bridge exceeds one-fifth the vessel's length) Lloyd's Rules require the sheer strake to be doubled for half the vessel's length. If, however, the bridge-house is substantially constructed, then the sheer strake need not be doubled in way of it (see Fig. 8, Plate 26).

With **an extensive 'midship superstructure,** however, it becomes practicable, and, of course, very desirable, to build it so substantially and of such uniform strength that, instead of being a source of weakness, necessitating reinforcement of the hull proper below, it **may strengthen the entire structure.** This superior system of bridge-house construction is now generally adopted, and so greatly does it increase the structural efficiency of the hull, that it may permit (by statute regulation) of a smaller freeboard. The modifications in the usual construction consist in plating the bridge deck, slightly thickening the side plating, double in place of single riveting the landings, and treble riveting the end joints.

In vessels whose length is great compared with their depth, the application of the above principle, of calling upon a 'midship bridge-house to contribute longitudinal strength to the hull, becomes almost imperative. Lloyd's Rules regard the matter in this way, for they require such vessels (those over 13 depths in length) to have a substantial superstructure extending over half the length amidships.

Art. 11. There is yet another weakness, sometimes observed in vessels which have a **superstructure of light shelter or shade-deck type.** It is a well-known principle that, should the addition to a girder of a slender outer flange increase the moment of inertia of the cross-section less than it increases the distance of the outermost layer from the neutral axis, such addition will not increase the strength of the girder; for, when subjected to a gradually increasing load, the slender outer flange will suffer excessive stress and fracture at an early period, and the resulting increase in duty, or greater stress thrown upon the remaining material of the now shallower girder, will still be less than that experienced by the slender flange when it fractured, so that further loading will be necessary to complete the failure of the girder. In accordance with this principle, the thin material of a light superstructure built upon a full scantlinged hull may suffer a more severe stress per square inch than would the upper plating (sheer strake, etc.) of the hull below, were the light superstructure not there; that is to say, contrary to what is usual in a girder, should the upper part of the hull fracture, the remaining part below, while having a slightly greater duty, would, nevertheless, suffer a smaller stress per square inch than the part just fractured did. In vessels having a long bridge-house or shelter deck this weakness is sometimes observed, the thin deck or side plating of the erection straining or fracturing, while the stout plating of the hull below shows no sign of stress.[1]

The fact that, in large vessels, a light superstructure, while itself suffering excessive longitudinal stress, may not contribute useful longitudinal strength to the hull, is sometimes kept in view; the possibility of rupture, with its inconvenient and damaging effects, being anticipated by introducing in the structural design, breaks in the fore-and-aft continuity of the light erection. It is obvious, however, that this is an unsatisfactory expedient, for between the breaks the original conditions still prevail, and the breaks themselves may cause undesirable concentration of stress on the hull proper. The proper remedy is to increase the massiveness and maintain the continuity of the superstructure, and this is the method now generally adopted.

Although, in the upper part of the hull, signs of **straining by excessive tensile stress** are not uncommon, evidence of **excessive compressive stress** is comparatively rare. This is no doubt due to the fact that considerably more yielding may occur in the latter case, for parts seriously strained may shirk the stress by buckling. Under tension, a taut part cannot shirk its work; it must resist, stretch, or fracture. But it is possible that weakness such as is shown by strained joints and loosened rivets may sometimes be as much the result of excessive compression as of excessive tension; for, of course, as a vessel passes over high waves, each plate and each joint is one moment affected by the one kind of stress and the next by the other. Of course, in the case of well-fitted butted joints the rivets are spared any participation in stresses of compression. Some interesting cases of excessive compressive stress at the upper-works are on record. One of these, a light paddle-steamer[2] designed for navigating smooth waters, on making her passage out, across the Bay of Biscay, met with long waves and broke in two, apparently from excessive compressive

[1] See Mr. Purvis' paper, "*On the effect of depth on the strength of a girder to resist bending strains*," *Trans. Institution of Naval Architects*, 1878; also Mr. Biles' paper, "*On the strength of large ships*," *Institution of Engineers and Shipbuilders in Scotland*, 1893–94.

[2] See the late Mr. John's paper, "*On the strains of iron ships*," *Trans. Institution of Naval Architects*, 1877.

stress at the upper-works, the structure here being in no way fitted to withstand severe stress. Another case is that of an oil-steamer,[1] built with a light shade-deck superstructure. In this vessel, the sagging tendency produced in still water by filling the 'midship oil tanks while the others were empty was such as to impose a stress of five tons per square inch on the thin shade-deck stringer plate. Had it been a tensional stress, it would not have declared itself, but, being compressive, it was sufficient to cause the thin plate to buckle down between the beams. The same effect (due to loading amidships) has frequently been observed in shelter-deck vessels and those having long bridge-houses. Of course, as just noticed, the actual failure of a light superstructure would not necessarily affect the integrity of the main structure below.

Art. 12. Consider now these matters which affect the **capabilities of the different parts of the hull in resisting tensile and compressive stresses.** The mechanical qualities of the structural material are, of course, an important factor. Their influence is more marked under tension than under compression. Thus, steel is a very superior material to iron, more reliable and uniform in every respect; but although under tension it is about 50 per cent. stronger, under compression the one may be about as capable as the other. When subjected to severe tensile stress, any brittleness or inferiority would greatly prejudice the safety of the structure, whereas under compression it might have little appreciable effect. Cast iron, for instance, is very brittle, yet when resisting compressive stress, as a column or pillar, it is superior to wrought iron. Nevertheless, when the material of a ship is subjected to excessive compressive stress, toughness is still a valuable quality; for when slender parts are subjected to excessive endwise compression they fail by side bending or buckling, long before the ultimate crushing strength of the material is reached, and in the case of a tough material such as steel, should actual buckling occur, it does not at once fracture in the disastrous fashion common to inferior iron. The mild steel of the present day is practically invariable in its excellent qualities, and so, in considering the strength of different ships, they may, in respect of material, be regarded as identical.

When a single part is subjected to **tensile stress**, its resistance per square inch of sectional area is the same whether it be thick or thin, a flexible plate or a rigid bar. In a structure, however, made up of numerous **parts**, it is an important condition towards effective resistance that all **should lie directly in the line of stress**; for if not, only those that did would offer resistance; any that were bent or buckled could give none until pulled taut, which, of course, would not happen until the adjoining ones, taut in the first instance, had stretched or fractured. The condition of such a structure might be likened to two mooring-chains, only one of which is taut. In the case of thin deck plating, for instance, supported by beams four feet apart, it is common to find that some of the strakes do not lie flat, but assume wavy undulations between the beams. The stringer plate, on the other hand, is usually quite fair, for it is held so by its attachment to the sheer strake, and, being extra thick, tends naturally to conform to the fair surface of the beams. Accordingly, it is always doubtful that thin deck plating would give, under severe stress, an effective resistance; the stringer plate would, but it might receive little assistance from the adjoining material. To ensure a maximum of efficiency, therefore, it is evidently an important matter that the component parts of the structure should be well put together, fairly with one another.

[1] See Mr. S. O. Kendall's paper, "*Strains on tank steamers*," *Trans. North-East Coast Institution of Engineers and Shipbuilders* for 1892-93.

In the case of **compressive stresses**, the resistance offered is also proportionate to the **sectional area**, but it is even more dependent on other matters. A direct disposition in the line of stress is here essential, for a part subjected to compressive stress is practically a pillar, and, of course, a bent pillar is of little value. When unfair parts are subjected to tension, the conditions, as the taut ones stretch, tend to improve, whereas, in the case of compression, any straining aggravates matters. Resistance to compression, unlike that to tension, is greatly influenced by the **stiffness or lateral rigidity** of the part, a quality governed by its thickness or sectional form and by its length between fixed points. When shell or deck plating is subjected to endwise compression, each part of a strake between two frames or beams acts like a pillar; if the distance between is small, the pillar is short, and therefore strong. The compressive strength of a strip of plating, so long as the distance between fixed points lies between, say, 50 and 100 times the thickness, varies practically as the thickness, and inversely as the length. This holds good, therefore, for such plated surfaces as are found in ships, say plating $\frac{1}{2}$ inch thick, held by frames or beams at intervals of 2 to 4 feet. According to a rough rule given by Rankin, the strength in tons per square inch may then be taken as equal to 400 multiplied by the thickness and divided by the length in inches. The compressive strength of deck plating per square inch of its sectional area may, therefore, be doubled either by placing the beams twice as close together or by doubling its thickness. The greater strength due to a double thickness occurs, of course, at every landing, and when these, owing to narrowness in the strakes, are numerous, the resisting capabilities of the surface may be greatly increased. The most effective way of increasing the efficiency of thin plating under compression is to stiffen it by union with rigid fore-and-aft parts. Even when the latter are discontinuous, and are therefore incapable themselves of offering resistance, they so stiffen the contiguous zone of plating as to make it impossible for it to shirk its work by side bending; failure would, therefore, occur by crushing, and, consequently, only under intense stress. In the case of the shell plating this effective reinforcement is well secured by the intercostal connection of the various keelsons, side, and deck stringers; in the case of deck plating there may be no corresponding parts, except in large vessels, where, as noticed later, intercostal girders are fitted under the beams.

Art. 13. Notice now the **comparative efficiency of the bottom and top parts of the hull in resisting** the tensile and compressive stresses due to **longitudinal bending forces.** The position of the neutral axis decides which flange of a girder shall suffer the more severe stress; it is the one more distant therefrom. The neutral axis (as regards longitudinal stress) is a horizontal line passing through the centre of gravity of the cross-sectional area of the longitudinally disposed material. If, therefore, the upper part of a vessel's hull were identical with the lower, it would be at mid-depth; but the upper part is much less massive, for there may be no deck plating, and if there is, it is thinner than the bottom shell plating, and much of it may be cut away by the hatchways; and, moreover, there are here no counterparts of the continuous keelsons, longitudinals, or inner bottom. Owing, therefore, to the preponderance of material at the bottom of the hull, the centre of gravity or neutral axis is always nearer the bottom than the top. Now, although the sectional area above and below may be unequal, the total tensile stress affecting one or the other (due to hogging or sagging tendencies in the hull) must equal at all times the total compressive stress (otherwise one would prevail, and result in a lengthening or shortening of the hull); consequently, owing to

the lesser material above, the average stress per square inch must be more intense here than below. Also, the maximum stress, located at the top edge of the sheer strake, is greater than the maximum below, acting at the lower edge of the keel, for it is proportional in either case to their respective distances from the neutral axis (Art. 573). It is thus clear that whatever be the tendency of the hull, to hog or to sag, the stresses, tensile or compressive, will be more intense at the upper part. But, further, in the case of the bottom, not only are they less severe, but the structural material is better disposed to resist them; the frames are always about 2 feet apart, whereas the deck beams may be four, which means, as already seen, that the bottom plating might sustain without buckling about twice the compressive stress that the deck plating could, and this irrespective of the greater strength per square inch due to its greater thickness and the valuable stiffening effect of the intercostal keelsons. As already seen, hogging stresses are usually more severe than sagging ones, and as it happens that the upper part of the hull suffers at all times more than the bottom, tension of the upper-works may be regarded as the most critical longitudinal stress.

Assuming that the material is equally efficient under tension and compression, the **most efficient girder** is that in which the **neutral axis is at mid-depth,** for here both flanges will suffer the same stress, and at the critical moment of failure both will give their utmost resistance. If the neutral axis were at, say, one-third the depth from the bottom, as it might be in a ship, the upper flange would suffer, at all times, twice the stress of the lower, and, accordingly, at a critical moment, when the girder was about to fail, the lower one, although perfectly capable, would be unable to exert more than half its power. Although in a ship, when regarded as a girder, there may thus be a serious discrepancy in the strength of the top and bottom, there is none when its all-round duties as a ship are considered. The bottom must be massive and strong, for, when in dry dock, it has to sustain the entire hull, and, should accidental grounding occur, the pressures may be local and intense; to qualify it, therefore, for such exceptional stresses, a large margin of strength is evidently essential. In the case of the upper part there is no demand for such massiveness, for here the governing requirement is a sufficiency of strength to resist the specialized stresses of tension and compression, which, acting only in one direction, and having in most vessels a comparatively limited range of intensity, may be provided against by less massive structural parts.

Art. 14. As vessels **increase in size,** so do the **bending tendencies** and resulting stresses of tension and compression **become more intense.** As already noticed, in passing from a small to a large vessel, a large augmentation of strength is obtained by plating the deck, otherwise perhaps only planked, which procedure, apart from the increased strength due to the added material, improves the efficiency of the hull as a girder by reducing the discrepancy in the massiveness of its top and bottom flanges. The proportion which a vessel's length bears to her depth is the governing element in deciding whether or not the deck should be plated; for, of course, if the depth were increased and the length unaltered, the hull would gain greatly in strength.[1] Apart, however, from relative dimensions, the

[1] In a solid rectangular beam the strength varies as the square of the depth, but in a box-girder, such as a ship, it does not increase so rapidly, for here an increase in depth does not similarly increase the sectional area of the material; the strength of the sides does increase as the square of the depth, for they are really in themselves slender rectangular beams, but that of the top and bottom is only increased by reason of the greater distance or leverage of these parts from the neutral axis, *i.e.* simply as the depth.

absolute size of the hull also governs the requirements as to plated decks; in a large vessel, for instance, two or three may be required, not necessarily for longitudinal strength, but for the general rigidity, transverse and longitudinal, which, as rigid horizontal diaphragms, they afford.

When a vessel's length is slightly increased without a corresponding increase in depth, it becomes necessary, apart from the introduction of so prominent a structural feature as a plated deck, to make other additions, with the specialized object of maintaining the longitudinal strength. The scantlings tabulated in **Lloyd's Rules** are based on the assumption that vessels built thereto are of normal proportions. If the length exceeds eleven times the depth the vessel is said to be of "**extreme proportions,**" and, according to the degree of disproportion—in conjunction with the absolute size of the hull—extra strength is required. The additional material is only applied to the 'midship portion of the hull, and principally at the gunwale. It takes the form of increased thickness of sheer strake and deck stringer; in extreme cases both of these, as also the strake below the sheer, may be doubled (see Figs. 12 to 14, Plate 4). As the upper sheer strake does at all times the most work, and under excessive longitudinal stress is the first part to fail, it may be regarded as the most vulnerable part of the hull, and should evidently be the first to be strengthened. As already seen, a prompt and effective resistance from the deck plating is not always assured, but in the case of the deck-stringer plate, connected as it is to the sheer strake, its efficiency under stress is little inferior to that of the latter, and more especially if it be thick (see Art. 150).

Art. 15. To give effective resistance, the **flanges of a girder** must be rigidly united to, and well stiffened by, the web. **If abnormally wide,** as in Fig. 9A, Plate 13, the marginal parts, remote from the web, would not act in concert with the central portion in direct union; they would be free to shirk their work by vertical straining or buckling. To secure efficiency in such a girder, another web might be introduced, making it of box section (Fig. 9C), or the flanges might be supported and stiffened by vertical staple angles and longitudinal edge bars (Fig. 9B). The bottom of a ship—viewed as the lower flange—is particularly efficient, because it is well stiffened by the keelsons or longitudinals, and is held to its work between the vessel's sides—the webs—by the rigid floors. The deck, on the other hand, resembles an abnormally wide and ill-supported flange. As a mere deck-platform, it is well sustained by the beams, but the flexibility of the plating between the beams, and of the beams themselves, is incompatible with an immediate and unflinching resistance to such stresses as are conveyed thereto only through the medium of the vessel's sides; the marginal parts, contiguous to, and rigidly held by the sides, act in prompt concert therewith; but towards the centre the co-operation becomes less and less perfect. In large vessels, where a special degree of efficiency is required, this matter receives particular attention. In the ss. *Great Eastern* the upper deck was composed of two plated surfaces, held apart by longitudinal webs, as in a double bottom. In large modern vessels, and long, shallow, channel steamers, keelson-like intercostal stringers are fitted below the deck (see Fig. 18, Plate 12, and Plate 105). When firmly held by pillars, the efficiency of the deck as an upper flange is increased, for it is then fixedly held in the line of stress, and the flexible plating between the beams, stiffened by its direct connection with the stringers, cannot shirk compression by buckling. In large passenger vessels there is usually a long 'midship deck-house, the mere union of which with the deck plating may greatly increase the efficiency of the latter, and just at that part of the hull where it is most desired.

Art. 16. Practically all large steamers are now built with a **double bottom,** and the **great strength** which such construction affords renders unnecessary any reinforcement at this part, even though the length may be very disproportionate; so much so, indeed, that it may be **admissible to reduce the thickness of the outer bottom** (Art. 115). In vessels not provided with a double bottom, and whose proportions may be extreme, reinforcements may be required here as at the top. Usually, however, they are of a minor character, taking the form of increased scantlings in the keelsons, particularly in those at the bilge, and by fitting them intercostally where otherwise they may not be so; or, as an alternative sometimes adopted, the shell plating of this part may be thickened.

Art. 17. A **wood deck** can give little or no effective **resistance to tensile stresses;** the planks have no fore-and-aft continuity, and so, excepting the restraining effect of the frictional resistance of the caulking in the seams, they are free to strain and slip upon one another. The bolts holding them to the beams have but a poor clamping effect, for they do not fit tightly in the holes in the beams, and, as they pass through soft wood, they are free to incline under stress. The resistance of a wood deck under tension may, therefore, be **disregarded;** it all devolves on the steelwork. On the other hand, a wood deck may offer considerable resistance to compressive stress; but it is evident that the discontinuity at each butt, partly filled with oakum, must disqualify it from affording the rigid resistance necessary for an efficient co-operation with so unyielding a material as steel. Unless it be thick, a soft wood deck only begins to give substantial assistance when the steel structure is seriously strained.

When a **plated deck** is **sheathed with wood,** the lateral stiffness which the planks afford may greatly increase its power of resisting compressive stress. They prevent it from buckling, but, of course, to ensure this, the bolts must be disposed both at and between the beams. If bolted only midway between them, the plating might buckle upwards, by lifting the planks; and if held only at the beams, it would be free to buckle downwards between them (see Figs. 29 and 30, Plate 56). Usually the bolts are placed in rows, near the beams, in which case the plating does not secure from the planking the fullest possible assistance.

Art. 18. In the foregoing articles the vessel is assumed to be upright. **When inclined, the structural design of the hull, as a girder,** may undergo a complete change. If half turned over on her beam ends, the two sides, formerly the webs, would become the flanges; and, correspondingly, the deck and bottom, formerly the flanges, would become the webs. In an intermediate position there would be no distinct flange or web, all four parts would act partly as one and partly as the other. Of course, whatever the inclination, the neutral axis (as regards longitudinal bending forces) remains horizontal and continues to traverse the centre of gravity of the cross-section. It follows, therefore, that, as a vessel inclines, one gunwale and bilge recede from the neutral axis and the others approach it, and, consequently, while the liability to stress of the former increases, that of the latter diminishes. In an extreme case, if the inclination were such as to lower one gunwale level with the neutral axis, while this one would suffer no stress at all, the other, standing alone, would have to do the work of both, which, moreover, owing to the increased distance from the neutral axis, might be abnormally great.[1]

[1] The stress is increased (or diminished) in proportion as the distance from the neutral axis is increased (or diminished), but it is also reduced (or increased) in proportion as the moment of inertia of the cross-section is increased (or diminished); the result, therefore, depends on how these two factors vary, and which the more. The late Prof. Jenkins,

It should be observed that the most severe longitudinal bending stresses occur when a vessel is lying across waves, and as steamers do not usually roll unless more or less broadside-on, it is unlikely that they would be experienced simultaneously with an excessive heel. **Sailing-ships**, on the other hand, having a **chronic list**, may often experience these conditions. Compared with steamers, however, they do not suffer such severe bending stresses, for their proportion of length to depth is less extreme, and their cargo is usually well distributed fore and aft. In steamers the buoyant 'midship machinery space may, as already seen, greatly augment longitudinal stresses.

Although the **hogging and sagging forces experienced by a sailing-ship** may never be excessive, it may happen, if they should occur simultaneously with an excessive heel, that the hull would suffer, as a result of such concurrence, severe transverse stresses of a racking nature. If, when heeled over by the wind, a ship should at the same time lie across, and plunge into the troughs of the waves, the uppermost gunwale and lowermost bilge, being unconnected by a rigid vertical web, would tend to shirk the resulting tensile and compressive stresses by approaching one another, *i.e.* the hull would tend to collapse, as a whole, opening and closing the opposite angles of the 'midship section. In the absence of bulkheads this tendency can only be resisted by the stiffness of the connection of the deck with the sides and that of the sides with the bottom.

The foregoing emphasises the **importance of concentrating structural material at the gunwale and bilge.** In this respect sailing-ships receive special attention. The beam knees are made extra strong, and, in those over a certain size, the bilge strakes are systematically thickened; also, in those whose small size does not necessitate a plated deck, the beams are rendered more effective by diagonal bracing (Art. 153 and Plate 86).

From what has now been seen of longitudinal bending stresses, it is evident that in viewing a **ship as a girder**, it must be as one **of a unique type.** A girder for land purposes is designed to withstand specified bending loads, in one position; whereas, in a ship, the forces to which the hull may be exposed have no fixed magnitude, direction, or point of application. In the former, weight of structure is comparatively unimportant; the two flanges may be designed, with precision, to possess any specified margin of strength, and, in the case of a compound girder, even the properties of the steel may be suitably chosen—harder and stiffer for parts subject only to compression.[1] A large ship, on the other hand, must preserve its girder-like qualities, no matter how it may be supported, inclined, or tossed about by the waves; and, whether a cargo vessel, whose dead-weight carrying capacity is paramount, or a passenger vessel requiring speed, the weight of the structure must be the minimum compatible with ample strength against all combinations of stress.

who investigated this subject, found that the stress on the material of the hull, due to a hogging force, attained a maximum at an angle of 30° from the upright, and that it was then 20 per. cent. greater than when in the upright. See Prof. Bile's paper, *Trans. Institution of Engineers and Shipbuilders in Scotland*, 1893–94.

[1] In the case of the Forth Bridge, while the strength of the steel forming the tension members is a soft material containing 19 per cent. of carbon, that forming the compression members contains 23 per cent., giving a tensile strength of about 31½ and 35½ tons respectively.

CHAPTER III.

Art. 19. Transverse stresses tend to produce deformation of the hull by forcing its surface in or out, or by racking the form of the cross-sections; in their application and effects they may be widespread or local—more usually they are local. Their tendencies are illustrated in exaggerated form in Plate 2. They may be variously caused: by resting on keel-blocks in dry dock or by grounding; by the pressure of the sea on the sides and bottom; by the weight of localized masses of cargo not balanced by sea pressure from without; by the local collapsing effects of blows struck by the waves, accentuated by the vessel's plunging movements; by rolling of the hull and the racking pressures of broadside waves. It is intended to notice first those stresses which affect the bottom, and how the structure is here arranged to meet them.

The **bottom** is especially **liable to severe pressures**; in dry dock the whole weight of the ship, often with considerable weights on board, is borne through the keel; and at sea the fully laden hull is supported by water pressure acting, for the most part, on the flat of the bottom. In all vessels there is a chance of running ashore on a rocky or stony bottom, but as the forces then brought to bear may be quite irresistible, it would evidently be absurd to consider them in the design. With many vessels, especially small ones, grounding is a common occurrence, but only on the soft bottom of tidal rivers or harbours, where the supporting effect may be no more trying than that experienced in dry dock. The chance of touching a bank or bar is one common to all vessels, and while in some cases no injury may result, in others the bottom may be seriously damaged, due either to bumping by the waves, or to the circumstances of a falling tide, heavy localized cargo, or the hard, unaccommodating nature of the bottom. As this, however, like the previous case of running ashore, is a contingency that should never, and may never, occur, it hardly warrants consideration in the design. In practice, therefore, while providing a strong bottom, it is not sought to secure complete immunity from such accidents; sufficient strength to resist the stresses due to docking, or grounding on a smooth bottom in still water, being regarded as a sufficiently high standard.

In the following, the **bottom framework** of a vessel not having a double bottom (such as is still adopted in sailing-ships; see Plates 100 and 101) will be specially considered, for it illustrates better the kind of structural strength that is actually required. Double-bottom framework is specially considered in Art. 170 onward. As already seen, the bottom framework is specially massive; while above the bilge each frame is a comparatively slender bar, those on the bottom take the form of deep plate girders (the floors), spanning the distance from bilge to bilge. Agreeably with their duty as girders, they taper towards their ends, being deepest at the centre, where the bending moment, due to such pressures as may be occasioned by resting on the keel, is greatest. The straining effects to which they are liable are illustrated in Fig. 3, Plate 2, which depicts

complete collapse of a vessel's bottom through excessive grounding pressure; and although such a pronounced case of failure is, of course, rare, straining of the same nature is not uncommon.

Under local pressure the **floors** alone would not act efficiently or in concert, and so, to this end, the **keelsons** are introduced: one at the centre and, except in very small vessels, two at each side. Their primary purpose is to strengthen the bottom against local pressures, through their binding effect on the floors; by tying these together they establish continuity among adjacent ones, so that upward or downward thrusts, local in their application and directly affecting only a few, may be distributed and met by the combined resistance of several over a wide area. The centre keelson, being directly over the keel, where upward pressures are most intense, is more powerful than the others; it forms an internal keel, and, with the keel proper, may be regarded as the backbone of the vessel's bottom. Also, from its large sectional area, it affords considerable longitudinal strength to the hull as a whole. Although the floors are most capable in resisting vertical pressures, they would not alone stand up to their work; under severe stress they would shirk resistance by *tripping*, *i.e.* folding over sideways (as shown, Fig. 4, Plate 3). The keelsons check this tendency to a large extent, for, by holding the upper edges at a fixed distance, all must trip together. Under severe pressure, however, the floors, though held against tripping, would develop a tendency to buckle or bend sideways (as shown, Fig. 6), and as, immediately such bending began, their resistance would rapidly decrease, it is very necessary to check it at the outset. This is accomplished by fitting small fore-and-aft plates, termed "intercostal plates," betwixt the floors (as shown, Fig. 7). These are incorporated with the side keelsons of all vessels, excepting very small ones (in which, of course, the floors are comparatively shallow), their upper edges being united to the keelson bars, and their lower to the shell, by short angles. They are not connected to the floors, but as their edges are fitted in close contact therewith—an essential feature—they are perfectly efficient in holding them upright.

Apart from the increased efficiency which **intercostal plates** give to the floors, they enormously **increase the strength and stiffness of the keelson** as a fore-and-aft stiffening rib to the bottom. An ordinary side keelson, placed merely on the tops of the floors (Fig. 6, Plate 3), is flexible, and so can offer but poor resistance to deflecting stresses; but when united to the shell by intercostal plates (Fig. 7) it is at once transformed into a deep, rigid girder, the top flange of which is formed by the continuous bars, the lower by the contiguous strip of shell plating, and the web by the intercostal plates. Although the latter may have no fore-and-aft continuity, they nevertheless have all the necessary attributes of a web, *i.e.* they prevent any relative fore-and-aft movement of the two flanges; they necessitate mutual co-operation, so that when exposed to a bending force tending to upheave the bottom, while the upper flange is subjected to tension only, the lower suffers only compression. A connection to the floors, by means of short vertical angles (as in Fig. 3), would, of course, increase the strength of the keelson, owing to the fore-and-aft continuity so established; but with ordinary shallow floors the connection would be but a poor one. When fitted in conjunction with the important centre keelson a connection is always made.

Intercostal plates have also an important **duty as regards the shell**; as already noticed, they stiffen it against the buckling tendency resulting from fore-and-aft compressive stresses. They also support it against local pressures due to grounding. As a result of this not infrequent

casualty, the thin shell plating may be set up in wavy undulations between the frames, the latter declaring themselves like the ribs of a lean animal (Fig. 6, Plate 3); and, of course, when fixedly held by intercostal plates, such deformation may be prevented or greatly reduced.

Art. 20. The **transverse stresses** which a vessel may suffer **through sitting on her keel,** in a loaded or partly loaded condition, have been investigated, and with interesting results.[1] Fig. 3, Plate 2, illustrates in exaggerated form the straining tendencies that were found to exist as regards the floors and bilge. The cargo in the holds tends to bend down the ends of the floors and to increase the curvature of the bilge; this action is aided by the weight of 'tween-deck cargo and that of the upper part of the hull itself, all of which is transmitted to the ends of the floors, *viâ* the sides and bilge. The magnitude of the stresses suffered at each point of the floor, bilge, and side were computed for vessels of different sizes, when light, and when loaded up to the lower deck beams with coal. It was found that in a small vessel of 160 tons the tensile stress at the upper edge of the floor, at the centre line, was about 2 tons per square inch when light, and 8·3 when loaded; and in one of 2900 tons, 3 and 7 tons. The resulting deflection of the floor was found to be small, about $\frac{1}{2}$ inch. The tension gradually decreases towards the bilge, disappearing at the lower part of the curve; here there is neither tension nor compression, but only a shearing force due to the weight supported. Thence, upwards, the inner edge of the frame bar suffers compression, due to the closing tendency of the curve of the bilge; this gradually increases (with sudden accentuations at the termination of the floor or reverse bar), the maximum, when light and when loaded, being, for the small vessel, 2 and 4·8 tons, and, for the large, 2·5 and 4·9 tons. Above the bilge the compressive stress gradually diminishes, disappearing at the beam knee.

In **vessels having shallow floors,** evidence of severe tensile stress at the top edges of the floors is often observed as a **result of grounding;** in small iron vessels it is common to find the reverse frames fractured, and the floors cracked down from the upper edge; and the fracture usually occurs at joints of the reverse bar, at limber holes, or at rivet holes for the connection of the wash plates to the floors. The above investigation indicates the necessity of maintaining the strength of the frame and reverse bar at the bilge, by an upward extension of the floor plates. In cases where the bottom is set up by grounding, the occurrence of excessive compressive stress at the bilge is often shown by buckling of the inner edge of the frame, and more particularly the inner edge of any web frames that may occur at this part, for, of course, being deeper than the frames, they suffer more stress. When a floor plate bends upwards in the middle, its ends at the bilge may be conceived to act as pivots, the shallow frame bar having little restraining or holding effect. When, therefore, instead of tapering the floor and stopping it at the bilge, it is continued in its full depth round the bilge and up the side, as a web frame (Fig. 2, Plate 7, and Fig. 7, Plate 8), its resisting capabilities are at once greatly increased; for it then acts as a beam whose ends are fixed instead of free. (As noticed, Art. 575, the fixing of the ends of a uniformly loaded beam makes it about 50 per cent. stronger and five times as stiff, or, in the case of a beam loaded only at the centre, twice as strong and four times as stiff.)

Art. 21. The **stresses imposed on a vessel's bottom** through

[1] See a paper by the late Mr. Read, and Jenkins, *Trans. Institution of Naval Architects*, 1882, "*On the transverse strains of iron merchant vessels;*" also one by Mr. J. Bruhn, read in 1901, "*On the transverse strength of ships.*"

resting on her keel are **reduced** very considerably **by the pillars.** Without these, all the upper weights, 'tween-deck cargo, deck-houses, etc., would be transmitted to the ends of the floors *viâ* the vessel's sides and bilge; but, with a central row of pillars, that portion of the weight lying over them is transmitted direct to the keel. As, however, the beams are comparatively flexible, much of the weight they support would, as before, be transmitted down the sides. In vessels of considerable beam a row of pillars is usually fitted on each side; these are also useful in reducing the transverse stresses on the bottom and bilge; for, as by their means much of the top weight, otherwise transmitted to the ends of the floors, is conveyed to them near the keel—where the counter-balancing pressure occurs—it is productive of a comparatively small bending moment.

Art. 22. It is now intended to notice the **side framing,** the stresses affecting it, and the nature of the resistance which it offers. The bottom of the hull, as just seen, is liable to occasionable pressures of an intense character, to meet which a large margin of strength is required. The sides are never so severely tried, for they are subject only to sea pressures of a collapsing or racking nature, and to the concussive effects of blows struck by the waves. These may often be severe, but as they are widespread in their application, affecting large areas, they may be provided against by framework of a less massive description than that required for the bottom. Of course, the sides, like the bottom, are also exposed to accidental pressures of an intense character, due to collisions of all kinds; but as these may be practically irresistible, it would evidently be inexpedient to provide against them by special massiveness in the framing.

The side framing, unlike that of the bottom, is formed of comparatively flexible bars—the frames—backed up and bound together by the side or hold stringers. When strained laterally, the thin shell plating can offer little resistance; to provide this is the special duty of the frames. But although the shell in itself is perfectly flexible, its mere union with the frames at once gives to these an immense increase of strength and stiffness, for the strip of plating covering each one really becomes part of it, forming a wide outer flange and greatly increasing its strength and stiffness (Fig. 11, Plate 6). The entire side of the ship might, indeed, be regarded as composed of a contiguous series of flat, girder-like hoops.

When stiffened by the transverse frames and held at a fixed distance by the various decks, the vessel's sides are well able, under normal conditions, to resist all collapsing and straining tendencies. If, now, in a two-deck vessel, the **lower-deck beams** are **suppressed,** it is evident that the sides, being deprived of their support, could not give the same unyielding resistance. The upper-deck beams would prevent any collapse at this part, but the sides below might pant,[1] *i.e.* bulge in and out independently (Fig. 4, Plate 2), and when the vessel rolled they might sway together from side to side, or "rack," as it is termed (Fig. 8). It will be observed that, although both kinds of straining—panting and racking—are similar in that both involve bending of the side, yet the former may occur locally, and on one side only, whereas the latter involves more widespread deformation, and requires that both sides shall strain alike.

The **strength required in the side frames** depends on their length between the two fixed points of support, the floors, and the deck (A and B, Fig. 4, Plate 2); if doubled in length, say, by the omission of a deck at mid-depth, they would only be half as strong and only one-eighth as

[1] Ordinarily, the term *Pant* is employed in referring to the straining tendencies at the bows (described, Art. 107), but as it is a conveniently descriptive expression, it will be used here in its wider sense.

stiff, *i.e.* they would deflect eight times more under the same bending pressure. (It should be observed that, as water pressure is distributed, the longer frame would suffer a greater pressure than either short one.) It is evident, therefore, that a vessel's design, as regards the number of decks, has a commanding influence in deciding the strength required in the framing, for, according as there may or may not be a lower deck, the side frames may be short and strong, or long and yielding.

The **scantlings of the frames** as tabulated in **Lloyd's rules** are governed by a numeral, which is practically the girth of the vessel's 'midship frame, from gunwale to gunwale (Art. 41). Now, although in two vessels this measurement (and consequently the scantlings of the frames) might be identical, yet in the one the breadth might be small and the depth large, causing the frames of the bottom to be short, and those of the side long, and *vice versâ* in the other. In such cases, as regards differences in the length of the bottom frames, special reinforcements are not usually necessary, for as the floors have a large margin of strength, any small increase in their duty would not materially affect their general efficiency. In the case of the side frames, however, as their strength is more closely proportioned to what is actually required under normal conditions, even a small increase in the depth of the vessel's side may so increase their duty as to necessitate reinforcements (the suppression of a deck is, of course, another matter to that under consideration; the former involves so large an increase in the depth of side as to greatly augment the duty of the framework, necessitating, as noticed later, additional beams or modifications in the framework). Lloyd's rules provide for this by their special requirements as to side stringers, the number and size of which is regulated by the depth of the unsupported side in the hold. These requirements are exhibited graphically in Plate 4.

Art. 23. It will be well to notice here the difference and relative value of the two qualities, **strength versus stiffness** or rigidity (Arts. 573 and 574). The strength of a beam is measured by the greatest load it can support without breaking or becoming permanently misshapen; stiffness represents its unyieldingness, or its resistance to bending, under stresses within the elastic limit of the material (should the stress exceed the elastic limit, or, in the case of steel, about half the ultimate strength, the material of the beam would stretch permanently, the quality of ductility coming into play). Stiffness is, therefore, a very different quality from strength. Two beams might be equally strong, and yet differ greatly in stiffness; for instance, a rectangular beam 4 inches deep by 4 inches broad has the same strength as one 2 inches deep and 16 inches broad, but under the same load it will deflect only half as much. If the first is reduced in breadth to three inches, it will only have three-quarters of the strength of the other, but it will still be stiffer, deflecting only two-thirds as much. Also, variations in the size of a beam may affect the strength very differently from the stiffness; thus, while to reduce the length of a beam by half would double its strength, it would increase its stiffness eight times, *i.e.* it would only deflect one-eighth as much under the same load.

In a watertight structure like a ship, composed of numerous parts riveted together, **stiffness or rigidity** is **no less important than strength**, for, should perceptible yielding occur, the riveting and caulking might suffer. Parts which are associated together for the purpose of resisting the same stress should, as far as possible, be similarly stiff; for if not, the brunt of the work would fall on the stiffer. Thus, in the case of the two beams above mentioned, if placed side by side so as to assist each other in resisting bending pressures, the efficiency of the combination would

be very poor; for, although equally strong, the more flexible one would only give half the resistance of the other. If compelled by their union to deflect alike, the stiffer would break (or bend permanently) when the other was only strained to half the breaking point; and, of course, the premature failure of one would at once involve that of the other.

Art. 24. Notice now the **relative efficiency of** the two sets of frames, longitudinal and transverse, *i.e.* **of frames versus side stringers,** in stiffening the shell plating and supporting the sides against deforming forces. It is evident that **the most efficient stiffener** is the one which is strongest and stiffest, the former quality varying as the length, inversely, and the latter as the cube of the length, inversely. Now, the transverse frames are short compared with the side stringers, for they only extend from bilge to deck, whereas the stringers span the long distance from bulkhead to bulkhead, or where, as in sailing-ships, there are no bulkheads, their length is practically that of the ship. If, for instance, in a hold 60 feet long between bulkheads, and 15 feet deep, there were, say, only one frame and one side stringer, identical in scantlings, then, although both parts, when under pressure from without, would necessarily yield alike, the frame, being one-fourth the length of the stringer, would give 64 times more resistance. It is clear, therefore, that light side stringers, on account of their great length and consequent elasticity, cannot by themselves give much resistance to widespread straining forces. This, however, is not their function; their principal duty is to give local support through their binding effect on the transverse frames. If, for instance, only one frame of a series happened to be subjected to intense pressure, it would, in yielding, at once be backed up by the side stringer, which, being connected to and supported by the unstrained frame on either side, would, in this short length, be so stiff that rather than yield it would force these two frames to yield, and these in turn would similarly affect the adjacent ones, so that the resistance to the local pressure would be distributed and result in a minimum stress and straining of the side.

The form or **design of the side stringers** has, of course, an important effect on their strength and stiffness. The stiffness of a beam of rectangular section increases as the cube of its depth; so that when a stringer is formed of a wide plate (as shown, Fig. 12, Plate 4) it becomes a very stiff girder, having greater individual strength than a number of smaller ones composed of mere bars, and having, perhaps, a greater combined sectional area. When so stiff and strong it is capable, apart from its mere binding effect on the frames, of affording direct and useful support to the side, over large areas. On the other hand, as the principal purpose of the stringers is so to unite the frames as to necessitate mutual and simultaneous action, it is evident that a large number, placed more closely together, may, owing to the distribution of their stiffening effect, give a better general result. In later vessels built to Lloyd's rules, on the deep-frame system, a reduction is often made in the strength of the side stringers, and a suitable increase made in the strength of the more important frames, the latter being increased in depth, as described in Art. 26 (see Fig. 1, Plate 55, and Plate 105).

The above considerations as to the comparative efficiency of stringers and frames apply also to the **floors and keelsons.** The **relative importance** of these two parts is sometimes misapprehended; thus, if, as a result of grounding, the bottom should be set up from bilge to bilge (so as to bend the floors upwards, say, by an inch or so at the centre), the keel naturally assumes an upward curve, and as it is this deviation from the familiar straight line that alone catches the eye, it is commonly assumed

that lack of longitudinal strength in the keelsons has been the weak point, or primary cause of the failure; and so, to strengthen the bottom and compensate for any possible deterioration in the structure due to the straining, it is common, when making the repairs, to reinforce the keelsons instead of the more efficient floors.

Art. 25. In vessels which have a full complement of decks, so that the lowest is not far above the keel, the sides may receive from them such excellent support that comparatively slender framing may suffice; such framing is described as "**ordinary framing**," the scantlings of which are tabulated in Lloyd's rules. But although passenger vessels and those in special trades may have such decks, modern cargo vessels rarely have, the lowest one being dispensed with for the sake of an unrestricted, capacious hold. In such, therefore, to compensate for the withdrawal of the supporting effect of this deck, it becomes necessary to reinforce the side framing. There are three ways of doing this (exhibited graphically in Plate 4), all of which are in vogue: by hold beams, deep frames, or web frames.

In the **hold-beam system** the ordinary framing is retained, and the necessary supporting effect provided by retaining a few beams and the stringer plate of the lower deck, making them extra strong, placing the beams at wide intervals and more securely connecting them to the sides. Lloyd's rules in this respect are illustrated in Plate 4, and a 'midship section of a steamer built on this system is given in Plate 102 (see also Plate 9). The dotted lines in Plates 4 and 102 indicate the beams of the lower deck that are retained, and it should be observed that they may be placed at intervals of 16 to 20 feet, the greater distance involving a stronger stringer. The duty of these beams is, of course, to unite the two sides. They act both as struts and ties; as struts, they support the sides against any tendency to collapse under sea pressure; and as ties, they hold them together, so that the one cannot strain without the other, the strength of each in resisting one-sided pressures being thus practically doubled. When placed at wide intervals it is evident that, in the absence of an extensive connection to the side, the supporting effect of each beam would be localized at its extremities, so that the vessel's sides in the wide space between them would still be flexible and yielding; and, under severe pressure from without, the localized thrust of each beam might almost force it through the side. The required distribution of their supporting effect is obtained by the retention of the usual deck stringer, now termed the "hold-beam stringer," which, however, being no longer supported and assisted by numerous beams, must be reinforced for its more important duties (see Plate 9).

In spanning the long distances between the beams (Plates 9 and 102), and in supporting the intermediate side, the **hold-beam stringer plate** now resembles a series of bridge girders acting horizontally. In accordance, therefore, with the principles governing girder design, it is provided with an inner flange, termed the "face bar," which also serves the useful purpose of a stiffening ridge, without which the thin edge of the plate would be readily bent and damaged by cargo. Further, to hold it to its work, it is supported at alternate frames by brackets, which not only check any tendency to fold over and shirk resistance under horizontal pressures acting on the vessel's side, but support it against the weight of superimposed cargo (see Fig. 2, etc., Plate 9). The better to unite the hold beams with the side, the stringer is locally increased in breadth at each one by a gusset plate (the term "gusset" is generally used to signify a triangular bracket plate, usually horizontally disposed). Under severe

athwartship compressive stress, the beam, acting like a strut, tends to bend laterally, and in doing so may impose a severe side stress on the rivets nearest the edge of the stringer; the gusset plates, by virtually shortening the beam, improve its efficiency as a strut, and permit of a more extensive rivet attachment. The stringer also benefits by the gussets, for when subjected to lateral bending pressures from without, tending to deflect it between the beams, the greatest bending moment and straining effect is concentrated at each beam, tending to cripple the inner edge of the plate, and, of course, the gusset plates give valuable additional strength just at these points. They have also the effect of reducing the length of the stringer between each pair of beams, thus increasing its efficiency as a supporting girder to the side.

Art. 26. Consider now the **deep-frame system** of providing the necessary transverse strength where, in the absence of a lower deck, the sides would be too deep for ordinary framing (see Plate 4, also Fig. 6, Plate 6, and Plates 103, 104, and 105). In this, as also in the web-frame system, all beams in the hold are dispensed with, the framing itself being so increased in strength as to make the vessel's sides self-supporting. In facilitating the stowage of cargo, the entire absence of beams in the hold may, of course, be very advantageous. The deep-frame system consists simply in uniformly increasing the strength of all the frames, longitudinal and transverse. It is evident that if their scantlings are increased in proper proportion to the greater depth of side requiring support, the efficiency of the structure will be undisturbed by the suppression of the lower deck. Deep frames are merely those of ordinary type increased in depth by about 50 per cent. They may, like ordinary frames, be of Z (built or solid), channel, or bulb-angle section; when composed of frame and reverse bar, both parts are usually of the same size. The stiffness of a rectangular beam increases as the cube of its depth; when of Z or channel section the increase is not so rapid, for, of course, the sectional area of the flanges, the most effective parts, does not alter. It lies between the cube and the square. Thus, if a $6'' \times 3\frac{1}{2}'' \times .3\frac{1}{2}'' \times \frac{1}{2}''$ Z frame be increased in depth to 9 inches, *i.e.* made 50 per cent. deeper, while only 25 per cent. heavier, it will be 75 per cent. stronger and $2\frac{1}{2}$ times as rigid; under the *same* load it will only deflect two-fifths as much.

In supporting the sides, therefore, a comparatively small increase in the depth of the frames may greatly increase their efficiency. But as the withdrawal of the lower deck may increase the depth of side in the hold by 50 per cent., an increase of 50 per cent. in that of the frames is evidently not excessive, for as the side is subject to distributed sea pressure, the bending load on the frames may vary as the area of side, and so might also be 50 per cent. greater. With a view to increasing still further the strength and stiffness of such deep frames, their span from bilge to deck is reduced somewhat by raising the tops of the floors higher up on the bilge, and by increasing slightly the depth of the beam-knees. Whereas with ordinary framing the ends of the floors need only extend upwards to twice their normal, or rule, depth at the keel, with deep frames, Lloyd's rules require them to rise 25 per cent. higher. This refers to the bracket floors in conjunction with a double bottom (see Plate 4); if deep frames are employed in conjunction with ordinary shallow floors, they are made still deeper (Lloyd's rules require them to be half an inch deeper). That this is proper is obvious, for, owing to the gradually tapered ends of the floors (see Figs. 1 and 2, Plate 6), the frames only begin to receive rigid support therefrom at a point below their extreme ends, and so are virtually longer. It is evident that to secure the fullest advantage of the great strength of deep

frames, their attachment to the deck beams should be greater than that required with those of ordinary type; with this object, therefore, and also to minimize the span of the frames, Lloyd's rules require the beam knees of the lowest deck to be 20 per cent. deeper, *i.e.* three in place of two and a half times the depth of the beams. This is not required for the upper-deck beams in vessels having two decks, for, of course, the special strength of deep framing is not called for above the second deck.

In order that the **side stringers associated with deep frames** may give a proportionate backing-up or binding effect, they must be similarly strengthened. Lloyd's requirements in this respect are illustrated in Plate 4. The form of the side stringers adopted in practice varies considerably; some different designs are illustrated in Fig. 1, Plate 55, and Plate 105. Usually all are made alike, the supporting effect being then uniformly distributed. In view of the fact that the frames, unlike the side stringers, are capable of resisting racking stresses, and, owing to their comparative shortness, are much more efficient in resisting collapsing stresses (Art. 24), Lloyd's Register permits of a large reduction in the scantlings of the stringers, provided the scantlings of the frames are slightly increased. Such distribution of material is advantageous to the general strength of the hull, due to the fact just noticed, namely, that, owing to the greater capabilities of the frames, a slight increase in their depth or massiveness may give to the hull much more general strength than is lost by even a large reduction in the scantlings of the comparatively inefficient side stringers. The rule generally observed in this matter is to associate a 33 or 50 per cent. reduction in the sectional area or massiveness of the side stringers with an increase of 1 inch or 1½ inches in the depth of the frames. As shown in Fig. 1, Plate 55, and Plate 105, the stringers, when reduced in scantlings in this way, may be composed of a single large angle bar and an intercostal plate; and Lloyd's Register permits, in such cases, of the usual lug being dispensed with, the incorporation of so shallow a stringer with the vessel's side being ample without it. It is evident that this method of construction greatly simplifies the building work.

The **deep-frame,** as also the web-frame, system of construction has an important **advantage over the hold-beam system,** in that the side is not only strengthened against collapsing or panting tendencies, but also against side racking. With hold beams, although the fore-and-aft line of great rigidity which they establish may thoroughly check any panting movement of the sides, it cannot prevent them from racking together sideways, in the manner shown in Figs. 8 and 9, Plate 2. Each hold beam, by grasping the frame, checks the tendency locally, but the stringer plate between them can give little resistance, for it is free to twist and incline with the side.

Art. 27. The **web-frame system** of construction is similar to the ast, in that the framework is so strengthened as to render the two sides self-supporting, but, in place of uniformly increasing the strength of every frame, only every fourth, fifth, or sixth is increased, but very largely, for, by means of a deep web plate, it is transformed from a comparatively flexible bar into a strong and rigid girder (shown, in section, in Fig. 10, Plate 6, and Plate 106). It is evident that the strength and stiffness of such frames is very great; in supporting the side, they might almost be regarded as inflexible buttresses. Their size and distance apart is governed by their length or span, *i.e.* the vessel's depth below the lowest deck. Lloyd's requirements in this respect are illustrated in Plate 4, and a description of the practical details will be found in Art. 99.

Each web frame gives a vertical line of almost perfect stiffness, but if

they stood alone, the vessel's sides between, being stiffened only by ordinary framing, would be flexible as before. The association of such local stiffness and flexibility would, of course, be very improper; under severe pressure the flexible parts would yield, and, where checked at each rigid point, straining would occur, resulting in loose rivets, leakiness, or fractured parts. The necessary distribution of the supporting effect is secured, not by ordinary side stringers, but by placing between the web-frames powerful fore-and-aft girders, in construction practically identical with the web frames themselves, and in number according to the depth of side (see Plates 4 and 106). In supporting the intermediate frames, these serve a similar purpose to the light stringers employed with ordinary framing (they are still referred to as "side stringers"), but whereas the primary duty of the latter is to stiffen the side by means of their binding effect on contiguous frames, that of the former is to act the distinctive part of a girder. They are fitted in short lengths between each pair of web-frames, which, in supporting their ends, act the part of piers; and, as they are identical in massiveness with the web frames, the side is rendered uniformly rigid and strong throughout. When so wide as 18 inches, they require vertical support to hold them to their work, square with the side, and so for this purpose a bracket plate is introduced, midway between each web (Fig. 10, Plate 4, and Fig. 11, Plate 7); should the latter, however be only 8 feet apart, such support is unnecessary, for in so short a distance the face angles afford ample lateral stiffness. Various forms of side stringers are adopted; some of them are shown in Fig. 1, Plate 7, and are described in Art. 103.

Where the stringers and web frames intersect, the continuity of one or the other must be sacrificed, *i.e.* the web frames may be continuous and the stringers be severed, or *vice versâ*. Formerly the one method was as common as the other, and sometimes a compromise was effected by making the plate continuous and cutting the angles in the one, and contrariwise in the other. Now, the web frames are always preserved intact, and evidently this is the proper plan, for they form short girders, and are, therefore, capable of resisting both panting and racking of the side, whereas the stringers, being long and flexible, can alone give but poor resistance against collapse, and none at all against racking. To sever the frames, therefore, would be unwise, for it would hurt them greatly both as supporting girders to the side and as rigid piers for the ends of the stringers. It is sometimes argued that continuity in the stringers would improve the longitudinal strength of the hull; but they are not introduced to give longitudinal strength, and as they are near the neutral axis they would, in any case, be of little service. Although completely severed at each web frame, they are, of course, well jointed (see Plate 7), so as to secure at least the longitudinal strength of the light, continuous stringers that would be fitted if the vessel had ordinary frames; and although the strength at each joint may not be equal to that of the intact stringer, it is ample in holding their ends when they exercise their girder-like duty of resisting pressures from without.

Art. 28. As indicated in Plate 4, the web or deep-frame system (as set forth in Lloyd's rules) permits of the suppression of one lower deck; and so, as vessels with ordinary framing, when over 24 feet deep, require a third deck (or tier of beams), this is the largest whose entire side below the upper deck may be supported without beams. In **vessels over 24 feet deep**, therefore (this depth is now often exceeded), a **second tier of closely spaced beams** is required for the transverse strength of the hull, and this, irrespective of the type of framing.

Such tier of beams is not necessarily laid as a platform for cargo (see the open tier of beams in Figs. 1 and 6, Plate 10), but in vessels exceeding a certain size a second plated deck is required for the longitudinal and general strength of the hull. Any of the foregoing systems of framing may then be employed as before, but as a substitute for the third tier of beams normally required. The requirements as to web frames and side stringers are governed by the vessel's depth amidships; the depth at the ends, owing to the sheer, may be much greater, but, although the frames are not increased, an additional side stringer may have to be introduced, and, at the extreme fore end, "panting beams" (see Plate 10). In way of a quarter-deck the vessel's depth is usually increased by 4 feet (Arts. 50 and 160), and in order that the framing—of whatever type—of this part may be properly proportioned, its arrangement is regulated by the 'midship depth plus the height of quarter-deck (see Plates 104 and 109). At this part of the hull the maximum depth admitting of a single deck is 28 in place of 24 feet; but when 24 feet is exceeded special reinforcements are required, for not only must every fourth frame be an 18-inch web and an additional side stringer be fitted, but at least four powerful hold beams must be introduced; and further, to limit the racking stresses which, with sides so deep, might be excessive, a transverse bulkhead is required in this region, dividing in two the after hold.

The floor plate, web frame, and conjoined deck beam may be regarded as forming together a rigid hoop, encircling the body of the hull and capable of bestowing great strength against all transverse stresses; and, the better to fulfil this ideal, those beams to which the tops of the web frames connect are made extra strong and are provided with large bracket knees. Web frames are also largely employed to maintain the transverse strength where locally prejudiced by the severance of numerous deck beams, as in way of the machinery space and large hatchways (Art. 96).

Art. 29. The question as to which of the three, the **hold-beam, deep-frame, or web-frame system**, is the best is one not readily answered. The choice rests with the owner, and is usually decided by the special requirements of the vessel's trade. Web or deep frames have a great advantage over hold beams, in that they leave a clearer hold space for cargo; except when carrying bulk cargoes, such as grain or coal, the presence of beams in the hold causes trouble in loading and discharging, and gives rise to *broken stowage*, *i.e.* vacant spaces amidst the cargo. In some cases, when specially large masses, such as machinery, must be carried, it is found necessary to cut portions of the beams away, jointing them temporarily for the voyage—an objectionable expedient, because care may not always be taken to reunite them efficiently. Compared with web or deep frames, hold beams may give—in proportion to the weight of material used—greater support to the side against mere horizontal pressures. As regards racking stresses, however, they are inferior. Comparing the deep-frame with the web-frame system, as regards cargo stowage there is little to choose between; the former has the advantage of reducing the tonnage—this being measured to the inner edge of the frames or sparring. It is also superior in that the only projecting parts interfering with the stowage space are the side stringers, between which cargo may often be stowed; with web frames the small rectangular spaces betwixt the webs and stringers is usually lost.

The deep-frame system is structurally superior to the web, in that as all frames are identical they are all equally efficient; under stress they all strain alike and contribute the same resistance. With web frames there is an association of flexible and rigid parts. When exposed to severe stress,

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while the unyielding web frames might be strained beyond their endurance (the elastic limit of the steel), the flexible intermediate frames might suffer little stress, but simply bear upon the rigid webs through the medium of the side stringers. Nevertheless, in view of the high efficiency which accompanies any increase in the depth dimension of a girder, it is probable that, in proportion to the weight of material used, the web-frame system may give greater general strength and stiffness. The deep-frame system is becoming more and more popular. It has the important advantage of simplicity, for as all frames are alike—simple bars—they may be formed in the same expeditious fashion; and as the side-stringers are continuous, they involve a minimum of labour. Web frames, on the other hand, are so different from the others that they have to be made independently; they thus involve additional labour, and special fitting work is required at the joints of the side stringers.

In the design of some large modern vessels the great strength and rigidity obtainable from deep web frames receives special attention. To secure it in ample degree, web frames 4 feet, and even 5 feet, deep, pierced with large lightening holes, are all fitted fore-and-aft, at intervals of 20 or 30 feet (see Fig. 6, Plate 8). They are not, as with ordinary webs, associated with correspondingly deep side stringers, and they are fitted, not merely below the lowest deck, but right up to the gunwale. When so deep they act more in the manner of transverse bulkheads, or diaphragms, than as girders (they are often referred to as "*partial bulkheads*"), and thus give immense rigidity to the hull as a whole; so much so as to relieve the ordinary frames of much of this duty, leaving them the subordinate one of giving local stiffness to the shell plating, in view of which it becomes admissible to reduce their number by an increased spacing. In large high-powered vessels web frames of this type are often fitted in way of the machinery space in the 'tween decks, where a maximum of transverse rigidity is required (Art. 96, and Fig. 5, Plate 8).

Art. 30. The side framing in the upper 'tween decks has a lesser duty than that below, for it is not subject to sea pressure, it has no 'tween-deck cargo to support, and, owing to the shortness of the span between the two decks compared with that between the lower deck and the vessel's bottom, the frames are naturally stiffer and stronger. The stresses to which this part of the side is liable are the occasional local pressures due to blows from the waves or flying masses of water moving at high velocity, and horizontal racking stresses due to rolling. These may often be severe, and in certain types of vessels must be provided against, but in most cases lighter framing suffices for this part. The reduction is usually made by stopping alternate reverse bars at the second deck, or tier of beams. In the case of an awning deck vessel a still greater reduction is admissible, for in these all the reverse bars may stop short at the second deck, the frames above being mere angle bars; and similarly with the side framing of a bridge or poop. In an awning-deck vessel, as the upper 'tween-deck portion of the hull stands well above the sea level, it is little exposed to the violence of the waves, and as the awning deck is not intended to support heavy weights, such as deck cargoes, a light construction throughout is admissible. Large sailing-ships, unlike steamers, are specially liable to racking stresses; they have no transverse bulkheads, and when heeled forcibly over by the masts, with one side submerged to the gunwale and the other well out of the water, the upper part of the hull may suffer severe one-sided pressure of a racking nature; in such vessels, therefore, no reduction is made in the side framing of the 'tween decks.

The **distance between the decks** has, of course, an important

bearing on the strength of the vessel's side. As regards stresses of a collapsing nature, due to sea pressure, the best position for the second deck (in a vessel having two) would evidently be at, or below, mid-depth; but in the absence of special compensation there are several circumstances which may render such a position undesirable. In a large cargo vessel so great a weight of cargo might be placed upon the 'tween deck as to necessitate extra powerful beams and pillars; and, should grounding occur, the stresses suffered by the framing at the bilge in supporting so much weight might be excessive. Further, large vessels require a second plated deck, and, of course, for the purpose of longitudinal strength, it should be placed not at mid-depth, *i.e.* near the neutral axis, but near the top of the hull. In practice the distance between decks is **usually limited to 8 feet**, this being the maximum height of side which, with the usual framing, is found to be compatible with sufficient strength and stiffness. In many vessels, however, 8 feet is exceeded, the side framing being suitably reinforced. In passenger vessels, for instance, where ample head-room in the cabin spaces is very desirable, the second deck may be as much as 10 feet below the upper; but in such cases, not only must the full strength of the frames be maintained, but a powerful side stringer or web frames must be introduced between the two decks. In cargo vessels having a similar height of 'tween decks the scantlings of the beams of the second deck and of the pillaring must be increased, to enable the deck to support the large mass of 'tween-deck cargo.

When the frames are of solid type, *i.e.* of Z, channel, or bulb-angle section, they cannot be so readily reduced in massiveness in the upper 'tween decks as when they are composed of frame angle and reverse bar, for the inner flange must be cut off (see Plate 107). Sometimes this is done, but more usually it is not, in which case advantage may be taken of the superabundant strength by slightly increasing the height between decks, this in many cases being advantageous as regards the stowage of cargo. Similarly with deep frames; in large vessels their greater strength is only called for by the absence of a third deck, and so (as in the case of web frames) their full depth need not be maintained above the second; here also advantage is often taken of the circumstance by increasing the 'tween-deck height a foot or so beyond the usual limit of 8 feet.

The **stopping of alternate reverse bars** at the second deck is **not conducive to efficiency**, for, with an alternation of flexible and rigid frames, the side does not receive a uniform stiffening effect; under excessive stress the slender frames, bending readily, escape the work and throw it on the stiffer ones. This, of course, is undesirable, and is only admissible on the score of simplicity and expediency; for while to stop all reverse bars at the second deck would too much reduce the strength, to extend all to the upper deck would create an excess. When the upper-deck beams are placed on alternate frames, the frames between, having their ends unconnected, are less efficient than the others. Regarding the frames as beams, spanning the distance from deck to deck, while those at the beams have both ends fixed, the others have only one; and, accordingly, if both were of equal scantlings and were subjected to a distributed load, the latter would only be about two-thirds as strong and half as stiff. The discrepancy may be minimized by the circumstance that the frames which are rendered strong by the beam attachment are those whose strength is reduced by the absence of a reverse bar. Nevertheless, it is evidently wrong so to dispose the beams, because it neglects the possibility of securing a high degree of transverse strength; for by placing them on the strong frames, the greater capabilities of the latter are utilized, not only

as stiffeners to the side, but as forming with the beams rigid knees against racking stresses. In sailing-ships it is not uncommon, as a result of racking stresses, for the slender frame angle to fracture just below the beam knee; if there were a reverse bar on the frame this could not happen (see Art. 33). In view of the above, Lloyd's rules now require the upper-deck beams to be on the strong frames. In warships and extra deep single-deck vessels, the tops of all frames are connected to the deck stringer, if not by beams, then by bracket plates or lugs. A bracket not only increases the efficiency of the frame but that of the stringer plate also, for, being held thereby rigidly in line, its efficiency under longitudinal compressive stress is greatly improved. When the beams are placed on every frame, as is often the case, each frame is, of course, well held, and when all the frames are maintained of full scantlings, the very desirable condition of uniformity in strength and stiffness is secured.

As already noticed, the limiting depth of 24 feet for single-deck vessels is now often exceeded, a depth exceeding 28 feet being often attained. In such cases the strength of side to resist the collapsing effect of sea pressure, and the racking and straining tendency of rolling movement at sea, may be secured either by extra-strong deep framing, or by web frames or widely spaced hold beams. The hold-beam system is the lightest, especially when the beams are placed about mid-depth, for as the vessel's sides are then supported well under water, where the greatest sea pressure occurs (the centre of fluid pressure is at two-thirds the depth of side below the waterline), the side frames are relieved of so much stress that a large reduction in their scantlings becomes admissible. The shortening of the lower part of the frames is, of course, accompanied by an increase in their strength and stiffness, the former varying as the length inversely and the latter as the cube of the length inversely. If web frames are employed in conjunction with hold beams, a still further reduction in the scantlings of the intermediate frames may be made. In vessels so constructed the hold beams, web frames, and pillars may be advantageously designed in the manner illustrated in Plate 111. Deep framing, if adopted, must be very massive to secure the necessary rigidity of side. In a vessel 28½ feet deep, for instance, a suitable size for the frames and reverse bars is 8 by 3½ by ½ inch, making a girder 12½ inches deep, the reverse bars being doubled with a 3½ by 3½ by ½-inch back bar, and extra deep beam knees being fitted. The side stringers in such a case might be four in number, each formed of a 6 by 6 by $\frac{29}{32}$-inch angle bar, and an intercostal plate (as shown in Plate 105). Vessels of the above type are, of course, only suitable for cargoes not liable to be damaged by pressure; and it is well to observe that the tank top should be well stiffened and supported, so that it may not strain under the heavy load of superincumbent cargo.

Art. 31. Notice now, more particularly, the nature of **racking stresses** and their straining effect on the structure. They may be variously caused; through the vessel rolling in a sea-way and perhaps suffering at the same time longitudinal bending stresses (see Art. 18); or as a result of an excessive heel, through shifting of the cargo in heavy weather; or they might occur through taking the ground with a heavy list when loaded. Figs. 8 and 9, Plate 2, depict a vessel rolling heavily at sea, the deformation of the transverse sections, due to the racking stresses so induced, being shown in greatly exaggerated form. Towards the end of each side swing the momentum of the mass of the upper part of the hull and of the 'tween-deck cargo is not all brought up by directly opposed water pressure, but by pressure acting lower down; the top weights thus tend to continue their movement and carry with them the upper part of the hull, causing it

to sway sideways relatively to the lower. Each swing to starboard tends to close the angle formed by the deck with the starboard side, and each swing to port to open it; and, being thus constantly reversed in direction, the straining effect is the more trying. Sailing-ships are particularly exposed to such racking stresses, for they are constantly heeled over by the side pressure of the masts, and the hull has not the stiffening effect of 'midship bulkheads. As illustrating the tendency of such straining, the well-known case of fractured scupper pipes may be mentioned. At one time these were led through the deck with a straight inclined lead through the side below, and, when so designed, any slight alteration of the angle formed by the deck with the side caused rupture of the pipes, to the damage of cargo and danger of the ship.

The liability to suffer racking stress through rolling is greatly dependent on the vessel's proportions and on the nature of her loading; a broad vessel, having heavy cargo stowed low down, or one floating light, in ballast, will roll, not through large angles, but in a violent, spasmodic manner, causing severe stresses throughout the structure. Sailing-ships, when loaded too stiffly, have been known to roll so violently as to jerk the masts overboard. On the other hand, a narrow ship, uniformly loaded, may be crank, or insufficiently stiff; according to the character of the waves encountered—their length or period—she may hardly roll at all, or do so excessively and dangerously, but with an easy motion not likely to strain the structure.

The racking forces that might be occasioned by lying at rest on the ground are shown in Fig. 5, Plate 2. The weight of the upper part of the hull and deck cargo is upborn by the vessel's sides and pillars; their supporting thrust, however, is an inclined one, which, of course, cannot alone balance the vertical pressure of the weights. But the latter forces, as shown by the two arrows FF, are each equivalent to two separate forces, f_1 and f_2, the former of which, acting parallel to the pillars and side, is balanced by their direct thrust, and the latter, acting along the beams (the racking force), is balanced by the resistance of the structure to such deformation.

Art. 32. Racking stresses and their distorting effect on a vessel's cross sections may be conveniently **analyzed** by considering the case of the rectangular frame shown in Figs. 10 to 12, Plate 2, composed, say, of small flexible rods, the upper and lower ones of which, acting respectively the part of a beam and deep floor plate, may be assumed to be rigid. In Fig. 10 the upper corners (the beam-knees) are pivoted; under a racking force, or couple, represented by the two arrows, the sides act like one half of a beam (completed by the dotted line) with free ends and loaded in the middle; the curvature, or straining effect on the material, is greatest at the lower corner (the bilge), and diminishes gradually to zero at the top. In Fig. 11 the beam is connected rigidly to the sides, a circumstance which not only alters the contour of the deflected sides, but greatly reduces the amount of deflection. Each side now acts like one half of a beam (completed by the dotted line) having both ends fixed. The restraining influence, formerly exerted at the lower corners only, is now also exerted at the upper, so that the sides are compelled to take a double bend. The curvature, or straining effect, is greatest at each corner; at mid-depth it disappears, for there is here no bending tendency, only a shearing force. By so fixing the upper corner the total deflection or racking deformation of the side (as measured by the distance AB) is reduced to one-quarter of what it was formerly; this being the comparative deflection of a beam (loaded at the centre) with fixed ends and one with ends free. In a similar way the strength of the side, *i.e.* the

racking force it could bear without injury, is doubled. In either case, if the length of the side were altered, the deflection would vary as the cube of such alteration and the strength as the first power inversely. For instance, if the depth were reduced by half, the deflection under the same force would be one-eighth. Fig. 12 shows two such half-depth sections superposed, forming, as shown, the section of a vessel having a second deck at mid-height, and as the deflection of each is one-eighth of the full depth section (Fig. 11), that of both combined is one-quarter; that is to say, the introduction of a second beam at mid-depth has the effect of reducing the racking deformation to one-quarter of what it would be with one deck. Similarly, if the second deck were at one-third the depth from the top, one-quarter would become one-third.

Art. 33. It is evident that mere strength of side framing is not necessarily accompanied by a good **resistance to racking**, for if the **corner connections** were weak, say pivoted, there would be none. Theoretically, the strength of a part designed to resist a bending stress should be proportioned at each point to the relative intensity of the bending moment. At mid-depth of the side in Fig. 11, Plate 2, there is no bending moment (the frame here is straight for a short distance), and so, evidently, as regards racking stresses, strength at this point would be of no value. Thence the bending moment gradually increases; it attains the maximum at the corners, and so, for the greatest efficiency, the strength here should also be greatest. The corners are, therefore, the vulnerable parts, and, as noticed later, their efficiency is carefully considered, especially where severe racking stresses may be anticipated, as where the second deck is suppressed in favour of web or deep frames.

If a frame and its conjoined beam formed one bar with sharply bent corner, the strength, in one respect, would be perfect, for the material would be continuous, without break or weak spot. Virtually, however, there would be a weak spot, because, when exposed to a stress tending to open the angle of the deck with the side, fracture would occur in the corner, and while the bending moment would be greatest at this point, the strength or moment of resistance of the frame and beam would be no greater here than elsewhere. Further, the mere abruptness of the junction of the frame with the beam would create a weakness, for the straining tendency would be concentrated at this point. The introduction of a beam knee at once greatly increases the efficiency, because, although not altering the intensity of the external straining forces, it relieves the frame where formerly most severely tried. The vulnerable place is then in the frame or beam at the extremities of the knee; but as there is here no sharp angular juncture, and as at these points the external racking force has a lesser bending effect, one which formerly would have been excessive may now be of comparatively little importance.

The **rivets binding the beam knee** to the frame are the medium through which all stresses affecting the one are conveyed to the other; they must therefore be properly proportioned to the work. Theoretically, as regards racking stresses, only two rivets might suffice, one at the top of the knee and one at the bottom (Fig. 1, Plate 2); their sufficiency, however, would depend on their distance apart, *i.e.* the depth of the knee. If two feet apart instead of one, they would resist without failure twice the racking force, for their leverage, or moment of resistance, would be twice as great. But, of course, there must be numerous rivets, for they are exposed to various direct and indirect shearing stresses; and, apart from the question of strength, the two faying surfaces must be bound intimately together (Arts. 289 and 466).

Under a racking or panting force tending to alter the angle of the deck with the side, the **lowest rivet in each beam knee** suffers the greatest stress. In Fig. 1, Plate 2, the frame may be regarded as a simple lever. F is the external force, say, sea pressure; the lower rivet, subject to a shearing force, f^1, is the fulcrum; while the resistance, f^2, offered by the upper one (*i.e.* the shearing force affecting it) is the load. It is at once evident that the shearing force at the lower rivet, or fulcrum, is equal to the other two combined, for it is the only one acting against them, to the right. If the three forces are equidistant, as shown, the lower rivet must suffer twice the stress of the upper; if the lower rivet be placed twice as near the upper one, as shown in Fig. 2, and the force F be the same, the stress on both rivets will be increased: that on the lower one will be doubled, and that on the upper trebled. If a third rivet were introduced just above the lower one, the pair might be regarded as together forming the fulcrum; but although the lower one would be much relieved, it would still suffer the greatest stress. It is evident, therefore, that to secure a good attachment of the frames to the deck, *depth in the beam knees*, giving them a widespread grip of the frames, is essential.

In the case of **sailing-ships**, it is common to find, after a trying voyage, that the **riveting of the 'midship beam knees** has become loose, and more particularly the lower rivets. The beams at the ends of the 'midship hatchways are the most **liable to strain** in this way, due to the greater work imposed on them by the absence of adjoining through-beams; also those in way of the masts, where subject to special thrusting effects. Evidence of the continued working or sliding of the beam-knees on the frames is often given by small accumulations of powdered rust lying on the edges of the sparring directly under them. As a rule the upper-deck beams suffer more than the lower, owing to the greater exposure of the upper part of the hull to racking pressures as the ship heels over in the waves. More rarely, in place of the rivets, the frame just below the knee (if not provided with a reverse bar) or the knee itself, gives way; in the case of the knee, the fracture occurs in the throat, it may be in consequence of inferior welding, or of the knee being badly formed, with a throat too sharp and narrow. The lower-deck beams restrain the frames above them as well as below; here, however, the upper rivets in the knees still suffer less than the lower, for they are relieved of excessive stress by the gunwale bar attachment to the side. In some of the early iron ships the stringer plate on the 'tween-deck beams had no intercostal connection to the side, but merely one rivet at each frame in the continuous gunwale bar; consequently, as a greater duty was imposed on the beam-knee rivets, they strained, and the upper ones, being unassisted, suffered like the lower. When the beam knee is a triangular bracket plate, with a rivet connection to the beam as well as to the frame (Fig. 6, Plate 81), what has just been noticed with regard to the latter applies equally to the former; as a rule, however, the attachment to the beam is more secure. Various practical details in connection with beam knees will be found in Art. 133.

Art. 34. The foregoing considerations regarding the efficiency of the connection of the **frames** to the beams also apply to **their union with the floors**; but, as the floors take a much more extensive grip of the frame, the tendency to strain is here much less pronounced. This is especially the case with ordinary floors, for owing to their gradual taper there is no sudden discontinuity in stiffness or flexibility, and so, little tendency to localization of stress. With a double bottom, the brackets connecting the side frames to the margin-plate resemble the beam knees, but, being large and having numerous rivets, they are naturally more

efficient. When a weakness does exist, it is in the **connection of the bracket to the tank margin plate.** In vessels of moderate size this is made with a single angle bar, which, being short, can only take seven or eight rivets. When subjected to a racking force tending to open the angle of the bilge (Fig. 8, Plate 2), the shell plating holds the lower edge of the bracket plate, so that, while the contiguous lower rivets experience little stress, the upper ones may suffer much. When pulled away from the margin plate, the short angle bar connecting the bracket tends to strain, as shown in Figs. 9 and 10, Plate 17, and, as a result, the watertightness of the rivets in the distorted flange may be prejudiced. In consequence of heavy weather and a trying condition of loading, it is not uncommon to find that straining has occurred at these places, causing leakiness in the tank, and more particularly in way of web frames, whose great rigidity accentuates the prejudicial effect of any weakness. In large vessels the bracket connection is made with double angles (for half-length amidships, or all fore and aft) which give, of course, a double holding effect; and Lloyd's rules require that certain of the brackets, at intervals (Art. 192 and Fig. 15, Plate 17), shall have gusset plates connecting their upper edges to the tank top. The latter are most efficient, for they bind the top edges of the brackets, just as the shell plating does the lower. And web frames must either have a gusset plate or double-angle connection.

Any tendency to strain by racking is chiefly confined to the 'midship portion of the hull; towards the ends the transverse sections become triangular, a form which cannot rack. Racking tendencies are most efficiently checked by the transverse bulkheads; for as these form rigid diaphragms across the hull, they entirely prevent alteration of the transverse sections in their vicinity. All large steamers have 'midship bulkheads, and, consequently, unless the stresses are so severe as to cause these to spring or bend, any racking that occurs can only be of a local character.

Art. 35. Sailing-ships are particularly liable to **racking stresses,** and as they have no 'midship bulkheads, the structure is peculiarly susceptible to their straining influence. Forced over by the wind acting through the masts, the top part of the hull is subject to a chronic thrust to leeward. The heeling force is often severe, sometimes so excessive as to force the vessel on her beam ends, *i.e.* with a heel so great as partly to immerse the deck. This condition is often accompanied, or caused by, shifting of the cargo, and may, therefore, be permanent, unless the cargo be trimmed back or the masts go overboard. Such a circumstance usually occurs in heavy weather, when the straining effect on the hull must be severe; and should longitudinal bending stresses supervene, their effect, owing to the upraised gunwale and depressed bilge, may greatly accentuate the tendency to transverse deformation. Casualties of this sort, more or less critical, are not infrequent, and in order that the hull may withstand them without injury, as it should do if well and strongly built, special care must be observed to secure ample transverse strength, more particularly at the bilge and gunwale. The structural design of a large sailing-ship differs from that of a steamer in two important matters; there are no 'midship bulkheads, and only two tiers of beams. As shown in Plate 4, while a steamer, when over 24 feet deep, requires a third tier of beams or an equivalent in specially strong framing, a sailing-ship does not until over 28½ feet deep—a depth seldom attained in sailing-ships. It is evident, therefore, that, in the absence of these important parts, the hull of a large sailing-ship must have other compensating structural features, and more especially those which will provide strength against racking.

The following are some of the **structural features peculiar to sailing-ships,** and which are required by Lloyd's rules. In the first place, owing to the method of computing the numerals (see Art. 41), the scantlings of both the framing and shell plating of large ships are heavier throughout than in steamers. The top-side, being specially subject to one-sided pressures from the sea and from the masts, is strengthened (in ships over 75 framing numeral) by extending all the reverse frames to the upper deck. Also, further to stiffen the upper deck against extensive side bending, such as is indicated in Fig. 7, Plate 1, the deck beams, if not plated, are braced by diagonal ties (see Plate 86 and Art. 153), which at once give great strength and rigidity to the deck surface against bending in its own plane. All of the beam knees are made three times the depth of the beam, instead of two and a half times, as in steamers. The beams of the second and third decks are made extra strong, being one inch deeper than those of the upper deck. Further, in large ships (over 16,000 plating numeral), to strengthen and stiffen the bilge, the shell plating around it is increased in thickness by one-twentieth of an inch. And, in still larger vessels, the strake of shell plating in way of the beams of the second deck is thickened by the same amount.

It is only in large ships that the above reinforcements are introduced, for it is only in these that the particular stresses they are intended to meet assume importance. As noticed in Art. 42, the intensity of well-defined transverse and longitudinal stresses increases much more rapidly than the dimensions of the hull. In a **small vessel** they are comparatively unimportant, so that if designed only with regard to them, and with the same margin of strength as a **large vessel,** the structure would be so slender as to have little endurance against the deteriorating effects of **wear and tear** and the various undefined local stresses, the bumps and blows, to which small cargo vessels are particularly liable. The severity of such wear and tear is much the same in both large and small vessels, so that while in the former, with their more massive structure, it may be unimportant, in the latter, with their comparatively slender hulls, it is so important as practically to govern the scantlings. Accordingly, in proportion to her size, a small cargo vessel is necessarily more stoutly built, her superior all-round strength providing, adventitiously as it were, a good margin against stresses which, in a large one, might be critical.

Art. 36. Vessels which trade in the tropics are often provided with a **light shade deck or permanent awning** (Fig. 5, Plate 76). It is open around the sides, with provision, perhaps, for closing it with shutters in heavy weather, and is upborne by the rail stanchions, by pillars, and by the machinery casings or deck-houses. Now, although such parts are well able to support the vertical weight of the deck, they can give little **stability against side stresses;** should the vessel roll, the whole flying superstructure would tend to sway from side to side. In such cases the necessary transverse strength may be provided by disposing some of the 'tween-deck pillars diagonally (Art. 135).

Art. 37. Notice now the **structural features of the upper deck.** The beams have a complex duty; as joists, they support the deck against the pressures that may be sustained from cargo, or from masses of water falling thereon in heavy weather; as ties and struts, they support and hold at fixed distance the vessel's sides, and, by their rigid union therewith, check racking tendencies in the transverse sections. They have a further duty, for when the hull is exposed to forces tending to bend it in the plane of the deck, they must act the part of a **connecting web for the upper portion of the sides as flanges**—the vessel's bottom serving

the same purpose for the lower. Such a bending tendency (in the plane of the deck) would occur if the vessel lay on her beam ends (Fig. 11, Plate 1); it is distinct from hogging or sagging, which refer to bending vertically, in the upright. It might also occur in heavy weather, through waves becoming momentarily heaped up on one side, or, locally, through the side pressure of the masts. In steamers the tendency may not often occur, but in sailing-ships it is more or less chronic, and may often be severe.

To analyze the **duty of the deck framing** in resisting lateral deformation of the upper portion of the hull, it will be convenient to imagine the **extreme case of a vessel lying completely over on her side,** say, poised on the crest of a buoyant wave, as in Fig. 11, Plate 1. If the deck were plated it would, like the bottom, be quite efficient as a web, and the box-girder-like aspect of the hull, however inclined, would be well maintained. When the deck is not plated, however, the beams alone would not form an efficient web. The principal duty of the web of a girder is (1) to hold the two flanges at a fixed distance apart, and (2) to prevent any relative longitudinal straining or slipping movement between them.

Figs. 5 and 6, Plate 1, represent part of the deck of a ship, acting like a deep girder, in which the sheer strakes (or top-side plating) form the flanges, and the deck beams the connecting web. Now, it is clear that, although the parallel beams conform to the first of the above requirements, they do not to the second, for while they hold the two flanges together and compel the same deformation or curvature in each, yet they permit of relative fore-and-aft movement; this is shown in Fig. 6, where it will be observed that the ends of the beams are no longer squarely opposite each other, *i.e.* squarely as regards the centre line (see beam D'E). In consequence of this, there is an entire lack of lateral rigidity in the deck surface; its resistance—in the absence of stringer plates—is simply that of the thin top-side plating to bending sideways, which, of course, is practically zero.

Notice now the effect of introducing **diagonal tie plates,** as shown in Fig. 12, Plate 1. As a connecting web for the two sides, the combination of beams and ties is now perfect (as regards the bending tendency shown in Fig. 13), for it prevents any relative longitudinal movement, and is now capable of transmitting longitudinal stresses from one side to the other. Should the deck suffer deflection, as shown in Fig. 13, the two flanges assume no longer the same curvature, but form the arcs of concentric circles, and, as the beams form radii thereto, they remain square to them and to the centre line; and further, while the one flange has suffered compression and has shortened, the other has suffered tension and has lengthened (the compressive and tensile forces due to the pull of the ties are shown by the small arrows *c* and *t*); that is to say, the entire deck surface may now be regarded as one deep girder, having its neutral axis at the centre line. Now, while the resistance of a plate to bending on its flat may be inappreciable, to stretch or compress it, ever so little, demands a stress of many tons per square inch; and as it is the introduction of the diagonal ties that has brought about this change of conditions, their value in giving lateral rigidity to the deck surface is at once apparent.

In resisting the distortion shown in Fig. 13, Plate 1, the ties all suffer tension (their pull or resistance to the tensile force is shown by the arrows T); for while the rectangular space ABCD in Fig. 6 has racked, so that the distance between points A and C has increased, the distance between corresponding points in Fig. 13 has not altered. Each diagonal tie acts, of

course, the well-known part of the sloping cross-bar in a barred gate. In Fig. 13 only one set of parallel diagonals is shown, and this would suffice if the bending tendency were always in the particular direction indicated; but if it were reversed, then, in preventing an approach of such points as A and C (as has occurred with the points B and D, Fig. 6), the ties would suffer compression instead of tension; and while a slender plate is perfectly efficient as a tie, it is quite otherwise if, as a strut, it is affected by compression. To provide, therefore, rigidity under either circumstance, two systems of ties are required, crossing one another as shown in Fig. 14.

In the foregoing, to simplify matters, it is assumed that there are no deck stringers. That these, however, are very essential is obvious, for if the thin top-side plating stood alone, it would buckle and shirk its work under quite a small compressive stress. Each stringer and combined sheer strake forms a strong T-section girder; but although very capable in resisting local deflection, their great length would be incompatible with an unyielding resistance to the widespread bending tendency depicted in Fig. 7, Plate 1. If united by beams alone, the resistance of the deck to bending in its own plane would still be that of two long flexible girders, each having its own neutral axis, and each yielding in the same fashion. Nevertheless, in the absence of diagonal ties, the deck stringer plates take their place in a measure; for, by holding the beam ends square to the side, they prevent their free movement as parallel connecting links, so that should relative fore-and-aft straining of the two sides occur, it must be accompanied by a double bend in each beam, as shown in Fig. 7; and it is evident that their resistance to such deformation (shown by the small arrows) has the same effect as that of diagonal ties, for it places the one stringer in compression and the other in tension. The efficiency of the stringers, in this respect, depends on their breadth; if narrow, the uncovered beams between them, being long and flexible, would give little resistance to slight lateral straining of the kind shown in Fig. 7; if very wide, so as to leave only a small portion of the beams uncovered, these, in this short length, would be stiff and unyielding. If, between two such wide stringers, a few of the beam spaces were plated, the cross-plating would evidently be equivalent to diagonal bracing.

The necessity for **diagonally bracing the beams** only arises **in sailing-vessels. In steamers** the normal position is upright, so that the chance of severe longitudinal bending stresses in the plane of the deck is remote; of course, in large and long vessels, when labouring in heavy seas, the tendency to twist and bend in all directions may be pronounced, but in such, the necessity for diagonal bracing is anticipated by the requirements of longitudinal and general strength, which involve the entire plating of one or more decks. In the case of a light shade or shelter deck, however, diagonal ties may be very beneficial. Sailing-ships, as already noticed, are subject to different conditions; forced over on their beam ends in stormy seas, the tendency of the upper works to rack, and thus bend the deck surface in its own plane, may often be great. In very small ships the general strength and rigidity of the hull is sufficient without diagonal deck ties; when over a certain size (15,000 plating numeral) they become essential (see Plate 86). In some of the earlier iron ships the absence of such bracing was indicated by straining of the deck planks, starting of the caulking, and leakiness.

Art. 38. In large **wood ships and composite vessels** similar **diagonal bracing** is required **on the sides** to strengthen the hull against hogging tendencies. In wood ships longitudinal strength is difficult to secure, for as they are composed of numerous planks, only united as a

continuous surface through the indirect medium of ill-jointed timber frames, longitudinal bending stresses are at once accompanied by marked fore-and-aft straining tendencies in the different planks, each one sliding endwise on its neighbour. Just as a beam composed of detached horizontal layers (see Fig. 2, Plate 114) is deficient both in strength and rigidity, so in a wood ship is the comparative freedom of the different parts to slide or strain upon each other incompatible with these qualities. With such pronounced straining of the various parts, the deformation soon becomes permanent; the hull gradually departs from the straight, so that it is not uncommon in old ships to find the original keel line hollowed up amidships by a couple of feet, the sheer line of the deck having become round in place of hollow. If the tendency to such sliding movement of the planks were prevented, the strength and rigidity of the hull would at once be greatly increased; it is checked to a great extent by the frictional resistance of the caulking, the perfection of which, in wood ships, is almost as necessary for the rigidity of the hull as it is for watertightness. It is found, for instance, that the tendency to alter shape by hogging becomes more pronounced as the caulking becomes soft. In the later days of wood shipbuilding the effective method of binding the various parallel parts—frames and side planks—together by diagonal bracing was adopted. In some of the earlier wood ships diagonally disposed logs were fitted within the timber frames, and in some the very efficient plan was adopted of doubling the outside planking diagonally. Latterly flat iron bars were employed, fitted diagonally from bilge to deck between the planking and the frames. As wood ships only suffer deformation from hogging stresses, only one set of parallel diagonals is employed, sloping upwards towards 'midship in both the forward and after bodies. In composite vessels, yachts and the like, a double system of diagonal ties is employed; in such there is, of course, no shell plating, only a sheer strake and a strake of plating at the bilge, and between these the diagonal ties are fitted, being riveted thereto and to the various frames.

Art. 39. As a sequel to the consideration of the **two kinds of stresses, longitudinal and transverse**, it will be well to notice in how far the one, more than the other, should **govern a vessel's structural design.** This question was much discussed in the early days of iron shipbuilding; at that time the question how to secure sufficient longitudinal strength held a prominent position, for in the prevailing wood ships its solution had been found difficult if not impossible. At that time, as now, the strength of a vessel, in its aspect as a long girder, was frequently investigated. The conditions assumed, however, were abnormally severe, a strength sufficient to withstand a high and dry position, poised upon rocks, being often taken as a proper and desirable standard. It was found, of course, that when built on the usual transverse system, large vessels could not satisfy such a test; but, even under more normal conditions, when lying across high waves, theoretical investigations indicated that the stresses approached dangerously near the elastic limit of the iron.[1] To secure the strength apparently lacking, it was urged that if much, if not all, of the framing material usually arranged as transverse ribs were disposed longitudinally it would, while still supporting and stiffening the shell, contribute advantageously to the longitudinal strength. Scott Russell, the designer of the *Great Eastern* and of some of the earliest iron vessels, was an earnest advocate of the longitudinal system;[2] he urged the abolition of all

[1] See the late Mr. John's paper, "*On the strength of iron ships*," *Trans. Institution of Naval Architects*, 1874.

[2] See Scott Russell's *Naval Architecture*, also the *Trans. Institution of Naval Architects*, 1862.

transverse frames and the substitution of continuous longitudinal ones; but, in order to give these transverse support, he required numerous cross bulkheads, complete and partial. By "partial" bulkhead is meant the marginal portion only, as in a web frame. In vessels of his design these took the form of intercostal plates fitted between the longitudinals, and connected at the joints by diamond face straps. The steamship *Great Eastern* was a notable example of the longitudinal principle. She had a complete inner skin, extending up to the lower deck. But, of course, this is not an essential feature of the longitudinal system; some vessels were built without it, the cargo being stowed right out to the shell between the longitudinals.

Although in these early days the **longitudinal system** of construction was regarded by many as the best theoretically, it was practically never adopted in merchant vessels. This was in great part due to the cost and tediousness of the work of construction. In actual building operations, until the main framework or skeleton of the hull is erected no other work can proceed. With transverse frames each one may be shaped and completed as an independent part, expeditiously, from the scrive board, and when all or any of them are prepared, they may be erected forthwith in a few hours, whereupon the plating and other work may proceed. With continuous longitudinal frames the scrive board cannot be used; they must be shaped and prepared in place, or by template moulds from the loft; and as each one is thus dependent on the one below, they must be dealt with consecutively and tediously, one at a time. Further, the necessity for numerous transverse bulkheads had a most deterrent influence; if the longitudinal system were adhered to in its entirety, these would have to be placed at fore-and-aft intervals of about the beam of the ship—a matter quite sufficient to prevent its adoption in ordinary cargo vessels. In warships a modified form of the longitudinal system was adopted from the first, and is still in vogue (see Fig. 5, Plate 16, and Plate 113). These, however, have little in common with merchant vessels; they have numerous bulkheads, and costliness and tediousness of construction are minor considerations (Art. 183).

Although the retention of the **transverse system** may formerly have been due to its greater simplicity and cheapness of construction, its continued adoption at the present time is the result of an assured knowledge of its greater fitness. The one claim of the longitudinal system is that it conduces to greater longitudinal strength; but the large cargo vessels of the present day require not only great longitudinal strength, but, in quite equal degree, great transverse strength; and evidently it would serve no good purpose to increase the one at the expense of the other. When arranged with transverse framing in the usual way, lack of the one quality does not, in practice, declare itself any more than lack of the other. In vessels whose length is great compared with their depth, and in which, therefore, special longitudinal strength is desired, it is readily and efficiently obtained by placing additional fore-and-aft material at the deck and bottom, *i.e.* in the most advantageous positions. To do so by disposing the major portion of the framework fore and aft would give but a poor result, for only those parts lying near the deck and bottom, remote from the neutral axis, would usefully assist. The earlier iron vessels had, no doubt, ample transverse strength, for they were small, narrow, of fine section, and usually had lower decks; modern cargo vessels are broad and full, and seldom have lower decks; they may have a clear hold, from upper deck to keel, 24 feet in depth, and it is evident that, with so large an area of unsupported side, the strongest arrangement of framing is essential. As already noticed, the shorter span of transverse frames—from bilge to bilge

and bilge to deck—makes them very superior in the matter of strength and stiffness to longitudinal ones; and they are well disposed to resist transverse racking stresses, against which the latter are practically useless.

When **cellular double bottoms** first came into vogue a modified form of the longitudinal system was adopted for the bottom framework. The ordinary system of framing had, in any case, to be modified; the two bottoms required to be rigidly united, and when this was effected chiefly by **continuous longitudinal plates**, the cross sectional area and longitudinal strength of the hull were increased (Fig. 6, Plate 16). This method of double-bottom construction is still adopted in warships, and for a considerable period it met with general favour in merchant vessels. As noticed in Art. 178, its principal features are the suppression of about half the number of transverse frames (or floors), placing them twice as far apart, and disposing the material so withdrawn in longitudinal plates, continuous or intercostal. Of late years, however, it has been realized that vessels so built are not more efficient than others having all the frames disposed transversely at the usual intervals (Fig. 4, Plate 16). Weight for weight, vessels built on the former system may have slightly greater longitudinal strength, but the latter are not deficient in this quality. When longitudinal weakness is indicated, it is at the top of the hull, where a little additional material is more effective than a great deal at the bottom. On the other hand, to withstand the ordinary contingency of grounding, with the least chance of injury, a maximum of strength in the bottom is always desirable. With a purely **transverse arrangement** of the framing, this is secured in the highest degree. Traversing the bottom from bilge to bilge, a frame forms a short girder, and so is both stronger and stiffer than a long fore-and-aft one; and when all are so disposed, at the usual close intervals, the shell plating is much better able to withstand severe upward pressures without buckling and bending. In large and long vessels, which are not liable to touch the bottom, and which require a maximum of longitudinal strength, a fore-and-aft disposition of some of the bottom framework may be advantageous, for, having several plated decks and thick top-side plating, their neutral axis may be at mid-depth, *i.e.* there is little discrepancy in the strength of the upper and lower parts of the hull, and so, whether placed at the top or bottom, any additional longitudinal material is thoroughly effective.

CHAPTER IV.

Art. 40. The structural design and scantlings of practically all merchant vessels are governed by rules drawn up by the various **classification or registration societies.** Of such institutions **Lloyd's Register of British and Foreign Shipping** may be regarded as the parent; it is by far the most influential, for of the total tonnage of all existing vessels in the world (steamers and sailing-ships of 100 tons and above) almost two-thirds has been built in conformity with Lloyd's rules, and more than one-half continues to bear Lloyd's class. Towards a proper appreciation of the usefulness of this society, and how much it has advanced the practice of naval architecture and the interests of shipping, it will be well to notice briefly its history. It originated about the middle of the seventeenth century in a body of underwriters, who met together in a coffee-house in London, owned by one Edward Lloyd. For convenience in transacting their insurance business, they kept a list or register of the vessels which came under their notice, in which the merits or demerits of each one were denoted by symbols, so that, although without personal knowledge of their condition, members might gain an idea of the risk involved should an insurance be sought on either hull or cargo. At first merely hand-written lists, these records assumed later the form of a register book, of which publication the earliest copy extant is one current for the year 1764. At that period the society consisted of underwriters only; each member had a copy of the register, but only for his own use, and he was forbidden to part with it.

Since the above early period the society has undergone many changes. As now constituted (the present constitution dates from 1834) it may be regarded as representing the shipping community of the United Kingdom, for it consists of a committee of merchants, underwriters, and shipowners, elected periodically in London and the principal outports. Correspondingly with the greater variety of interests represented, its sphere of usefulness has greatly extended. It publishes annually a register book, which contains, as is well known, an accurate and detailed description of practically every vessel afloat over 100 tons, or smaller if holding Lloyd's class; against each one is marked the particular class she holds with the society, also the date when last surveyed and found in an efficient state. To keep the book up to date, fortnightly supplements are distributed, giving any alterations in class, or surveys and repairs that may have been made. This book holds a unique position, and is referred to throughout the world by all connected with shipping.

The society also publishes (annually as regards steel vessels) a book of **rules, for the construction of wood, composite, iron, and steel vessels,** also one for yachts, for which class of vessel there is a separate register book. In every large shipping port throughout the world there are stationed practical surveyors, whose unprejudiced services are at the disposal of shipowners, for supervising either the construction of vessels or their repair. Also, to ensure that the steel used in the construction of

classed vessels shall be perfect in quality, surveyors are stationed at the various steel works to test the raw material before it is delivered to the shipyards. To ensure that the condition and seaworthiness of classed vessels are maintained, they are examined periodically, and upon the result of such survey depends the continuance of their class. These examinations are termed "special surveys." They are made every four years—the first when the vessel is four years old, the second when eight years old, and the third when twelve years old. The thoroughness of each survey increases with the age of the vessel; the third is particularly severe, the condition of the vessel being so thoroughly looked into, and made good where defective, as to permit of her class being maintained subsequently by another series of surveys, beginning, as before, with a No. 1. The second No. 3 special survey is the most severe of all, for when the vessel attains this age it is considered advisable to drill two or three holes in every strake of shell plating, to ascertain to what extent corrosion may have reduced the thickness. It is interesting to note that in vessels of this age which have been well kept up, there may be little or no reduction in the thickness of the shell plating. The various requirements of the special surveys are detailed in Lloyd's published rules.

Lloyd's highest class, signified by the symbol **A1**, has long been proverbial as symbolical of perfection. In the case of a steel or iron vessel a numeral is prefixed, **100, 95,** or **90.** A vessel classed **100A1** is one which conforms to the society's highest standard of strength and efficiency. If built with slightly thinner plating, or should deterioration not have been made good by repairs, she may only be eligible for the **90A** class, Practically all sea-going vessels are built to the highest **100A1** class, and are maintained therein by making good deterioration. For general trading purposes a lower class is a serious impediment, for it not only involves high insurance premiums, but may disqualify the vessel for certain cargoes. The above classification is given to vessels which—as formerly stated—are "fit for the conveyance of dry and perishable goods, to and from all parts of the world." Many vessels, however, are built for special purposes, for river or channel service; and as in such the strength and massiveness of hull ordinarily required would be unnecessary, they are built of lighter scantlings. Such vessels may still hold Lloyd's **A1** class, but there is no numeral prefixed, and appended thereto is a note of the limited trading for which, as classed vessels, they are eligible; and, moreover, the maintenance of a minimum freeboard may be a condition of such classification. Of the symbol **A1**, the letter **A** refers to the hull, the figure **1** to the equipment. Should a vessel be deficient in anchors, cables, etc., the figure **1** is omitted.

For **wood ships** the **symbols of classification** are more elaborate, because of the many different kinds of timber of varying durability of which they may be built, and of the inevitable deterioration which occurs with age. Steel and iron do not deteriorate; they may thin away by corrosion, but this may be prevented, or, if not, it may be seen and rectified: in such vessels, therefore, age gives little or no clue to their strength and stoutness. The age of a wood ship, on the other hand, may indicate fairly well her condition. All timber rots or loses its pristine stoutness, and the iron bolts and wood treenails become less and less trustworthy. Teak is the most durable of timbers. Vessels built of it are supposed to remain good for sixteen years; if built of fir, only for eight. The former receive the class **16A1**, the latter **8A1.** At the expiration of these periods the class expires; they may then receive a lower one if the hull is found, on examination, to be good, or is made so.

In the **early days of Lloyd's Register** there was no system of **rules for regulating construction.** The wood ships of that period were classed according to their age, the efficiency of their construction being only regarded in so far that only London-built ships—which had a reputation for excellence—were eligible for the highest class. Later, with a view to basing the class more fairly on the merits of the ship, rules of construction were drawn up, adherence to which was necessary to render the vessel eligible for the highest class. And to ensure that the rules were carried out, and that the workmanship was good, the society engaged a staff of practical surveyors.

The **first iron vessel** classed with Lloyd's Register was the *Sirius*, of 180 tons, built in 1837; but iron ships had been built for some time previously. With so novel a structural material, a considerable diversity of building practice prevailed, and some time elapsed before sufficient experience had accumulated to indicate precisely what were the best methods of construction, and what scantlings were compatible with a strong and efficient hull. By 1854, however, Lloyd's Register found it practicable and desirable to draw up rules to be observed in the construction of iron vessels intended for their classification. In accordance with these rules, iron vessels were classed—like those of wood—for a term of years: twelve, nine, and six, the particular one depending on the thickness of the shell plating and on the frame spacing. The scantlings then in vogue were exceedingly massive. This was a natural consequence of the experimental nature of the material; for experience was lacking as to its ability to withstand corrosion; and the intense local pressures that might be occasioned by grounding, while easily withstood by stout oaken planks, seemed likely to be critical in the case of thin iron plating. Some ten years later the first rules were greatly modified; the scantlings, which were found to give unnecessary strength, much in excess of that possessed by wood ships, were reduced; and as it was observed that deterioration by corrosion was preventable, and was not governed by age or time, classification by years was abandoned.

In 1870 an important alteration was made in the rules. Until then the scantlings were tabulated on the **basis of the under-deck tonnage**; they were tabulated in **grades**, one set of scantlings for all vessels ranging between 600 and 800 tons, another for those between 800 and 1000, and so on; so that a shipbuilder wishing to construct a vessel, say of 700 tons, would find the appropriate scantlings under the 600-ton grade. This tonnage basis was found to be inconvenient, however, and led to difficulties, for until a ship was completed and measured by the Board of Trade officials her precise tonnage was uncertain. It sometimes happened, for instance, that a vessel built under a certain grade would subsequently, upon measurement, be found to be larger than expected, placing her in a higher grade, requiring larger scantlings. To avoid such difficulties, to simplify the application of the rules, and better to take account of differences in the proportionate dimensions of ships of similar size, the present method—described later—of grading the scantlings under *numerals* or *numbers* was inaugurated. Since 1870 numerous alterations have been made in the rules, making them more specific and detailed, tabulating the scantlings, and stating requirements where formerly left to the discretion of the builder. Such alterations were, of course, only made when warranted by matured experience, and they followed, as a natural course, upon the adoption of new and widely different types of vessels.[1]

[1] The rules are published annually; those for steel vessels may be purchased for 5*s.* per copy.

A classification society such as Lloyd's Register is in a position to acquire experience of a most practical and valuable sort; for it not only supervises the construction of many hundreds of vessels in each year, but subsequently, throughout their existence, has them under constant survey. Should any weakness or defects develop, whether due to insufficient scantlings, bad workmanship, material, or design, the circumstance is carefully considered and recorded. Having, in this way, constantly under observation many thousands of vessels of all sizes and types, the practical knowledge acquired empowers the society to state with assurance what is required and what should be avoided in a sound structural design. It is sometimes urged that the shipbuilder should be the best judge of what are the best methods of construction, and of how much strength a ship should have; but to build and launch a ship does not prove her a success; it is only after some years of active service, having carried all sorts of cargoes in all kinds of weathers, that the efficiency of the structure may be said to be proved. In building a vessel of unfamiliar size and type, both the builder and the owner find in Lloyd's rules trustworthy data founded on wide and matured experience. It is sometimes asserted that, by formulating fixed rules, classification societies tend to restrict design and hinder progress. But departures from the rules in the building of classed vessels are only debarred when they tend to reduce strength and encroach on the margin of safety found by experience to be the minimum compatible with a sound and efficient ship. Many high-class vessels are built with very considerable modifications from the methods of construction set forth in the rules, but these are usually in the direction of increased strength and efficiency. It is evident that where there is any doubt as to the efficiency of departures from the usual practice, a classification society must exercise caution and circumspection; representing, as it does, the interests of owners, underwriters, merchants, and the general public, it is not for it to foster or originate new and untried schemes.

Art. 41. The numerals, or numbers, under which the scantlings in Lloyd's rules are tabulated are of two kinds. The **first, transverse or framing numeral**, is the number obtained by the addition of the vessel's depth, half breadth, and half girth.[1] It will be observed that this is practically equivalent to the vessel's girth or the length of the 'midship frame from gunwale to gunwale. These numbers are tabulated for vessels of gradually increasing size, and under each one are given the scantlings (found by experience to be appropriate to each size of vessel, or, rather, to each group of vessels of such slightly different sizes as are comprised between consecutive numerals) of all transversely disposed parts, the frames and their spacing, the reverse bars, floors, pillars, and transverse bulkheads. It is evident that the transverse dimensions of the hull must be the proper basis for deciding the particular grade, or set of scantlings to which the transversely disposed parts should conform.

The **second, longitudinal or plating numeral**, is simply the transverse one multiplied by the vessel's length (measured from the back of the stem to the front of the rudder post). This number, it will be observed, represents the surface area in square feet of a parallel-sided trough, having a cross section, roughly, that of the vessel's 'midship section; if multiplied by a suitable fraction (about $\frac{9}{10}$) it would give the area of the vessel's shell

[1] It has been urged that a fixed proportion of the sheer should be included in the above measurements, so that vessels having excessive sheer, and which, therefore, may load extra deeply and suffer extra stress, may have correspondingly large scantlings; and *vice versâ* in the case of those having little or no sheer. The absence of sheer in turret-deck vessels is taken account of in measuring the numerals, and it is probable that the above proposal will soon be adopted for all vessels.

plating. Under this numeral are tabulated the scantlings of all longitudinal parts, the shell plating, keel, keelsons, deck stringers, etc.

The following table gives the dimensions of vessels which correspond, roughly, with different numerals.

1st Number.	2nd Number.	Length in feet.	Breadth in feet.	Depth in feet.
25	2,000	80	13	6·75
36	4,000	111	18	9·75
51	8,000	157	26	13·5
63	12,000	191	32	17·0
72	16,000	222	36	19·5
81	20,000	247	40	22·0
87	24,000	276	42	24·0
90	28,000	310	47	27·0
95	34,000	358	50	28·5
104	40,000	384	54	31·0
112	50,000	446	56	34·0
123	60,000	487	61	37·0
130	70,000	538	64	39·0
137	80,000	584	65	42·0
143	90,000	630	66	44·5
148	100,000	675	68	46·0

It must not be supposed, as is sometimes done, that the thickness of the shell plating or other scantlings are based, in the first instance, on the mere **magnitude of the numerals**; for instance, the shell plating of a vessel whose second number is 20,000 is not twice as thick as it is in one having a numeral of 10,000. There is no fixed relation; in the former it is $\frac{11}{20}$ inch, in the latter $\frac{8}{20}$. The scantlings appropriate to various sizes and types of vessels were decided in the beginning more or less tentatively or empirically, and in course of time, as dictated by experience, they were suitably modified. The numerals may be regarded merely as a means of identification, to indicate, as it were, the general size of the vessel, and what scantlings are in her case appropriate. If all vessels, though varying in size, were of identical proportions and form, it would be a matter of indifference what the numerals were; a single dimension, the length, breadth, or depth, or the volume or tonnage, would serve equally well as a means of proclaiming the size, and what scantlings would be the most appropriate. But vessels vary greatly in form, and it is therefore no easy matter to devise numerals which, while simple of application, will form in all cases a theoretically correct basis.

Art. 42. Before considering the appropriateness of any particular system of numerals, it will be well to notice **how the scantlings of longitudinal parts, viewing the hull theoretically as a girder, should be governed by variations in the dimensions.** When poised upon waves, as in Fig. 1, Plate 1, the bending moment may be taken as proportional to the shaded area multiplied by the distance AB, *i.e.* the volume of the hull deprived of buoyant support multiplied by the distance of its centre of gravity from 'midships.[1] If, now, the vessel's length be increased, say doubled, then the volume, or weight, represented by the shaded area, having one of its dimensions doubled, would be twice as large; and, of course, the distance AB—between similarly situated points— would also be doubled. The bending moment would therefore be twice doubled, or four times

[1] It is assumed here that all vessels are fully laden with the same homogeneous cargo. Also, that the length of the waves is equal in all cases to that of the ship; but as short waves may be much steeper than long ones, it will be assumed that the height is constant.

greater, *i.e.* it varies as the square of the length. In order, now, that the fore-and-aft material of the hull, while resisting this greater bending moment, may suffer no more stress per square inch, its cross-sectional area must be increased in the same proportion, *i.e.* it must be four times greater. Associated with a double length, this would mean that the weight of the hull (neglecting some transverse parts) would be eight times greater; that is to say, it would vary as the cube of the length.[1]

If, now, the **breadth** of a ship **be increased,** say doubled, the bending moment would also be doubled, for the shaded area (Fig. 1, Plate 1), being twice as broad—athwartships—would represent an unsupported volume twice as large and heavy; that is to say, the bending moment varies simply as the breadth. In the case of variations in the dimension of *depth*, it is evident that these would not alter the bending moment, for when poised upon the same wave the volume represented by the shaded area would be unaffected by the depth of the hull above or below it. Also, should both the breadth and depth be altered, the bending moment would still only vary as the breadth.

Notice now **how the strength of the hull would be affected by a** simultaneous **variation in breadth and depth.** Assume that both are doubled, then if the thickness of fore-and-aft parts were unaltered, their cross-sectional area would also be doubled, for the deck and bottom would be twice as wide and the sides twice as deep. But their moment of resistance, *i.e.* the strength of the hull as a girder, would be four times greater, for not only would the horizontal plating be of double area, but, being twice as far from the neutral axis, it would have the advantage of a double leverage; and in the case of the sides, as they really form deep girders of rectangular section, their strength (which, in a rectangular beam, varies as the square of the depth), when doubled in depth, would also be four times greater (Art. 573); that is to say, with the same thickness of fore-and-aft parts, the longitudinal strength of the hull would vary as the square of the increase in the vessel's depth and breadth dimensions. Now, it has just been seen that the external bending moment, varying only with the breadth, would be twice as great, and so, with a hull four times as strong, the material would only suffer half the stress per square inch. To secure equality, therefore, the thickness of fore-and-aft parts in the enlarged vessel would require to be reduced by half; that is to say, the *thickness* would very *inversely* as the increase in breadth and depth, the *sectional area or weight being constant.*

It thus appears that if it be desired to maintain the same longitudinal strength in a vessel enlarged proportionately in both breadth and depth, the cross-sectional area, or weight of the longitudinal material, need not be increased, the greater bending moment due to the larger breadth being met by the greater leverage of most of the material about the neutral axis. Also, it has just been seen that an *increase in length* involves an increase in the sectional area of fore-and-aft parts proportional to the square of such increase; and this, observe, is the case whether only the length be increased, or with it the breadth and depth, the increase in the latter dimensions not involving any variation in the sectional area. To secure, in such a case, the proper sectional area of material, the increase in the *thickness* of the plating would depend on how much the breadth and depth were increased; if they were not altered, and the length were doubled, it would be four

[1] See Froude's paper, *Trans. Institution of Naval Architects*, 1874. In this investigation Froude assumed that the waves varied in height as well as in length, and, consequently, the bending moment was shown to vary as the *third power* of the length, and the weight of the hull as the *fourth* power.

times as thick; if all were doubled, twice as thick, the sectional area in both cases being the same.

Although the **foregoing theoretical conclusions** are correct within the assumed conditions, they **do not accord with what is found proper in practice.** This is readily explained; the reasoning wrongly assumes all vessels to be structurally identical; it neglects transverse and other stresses, which have a commanding influence in deciding the scantlings; and it assumes thin and thick plating to give an equally efficient resistance per square inch. That the conclusions are, practically, incorrect is evident; thus, in a vessel 200 feet long the shell plating is about $\frac{9}{20}$ inch thick; if it varied as the square of the length (and inversely as the breadth and depth), then, in a vessel 400 feet long and enlarged, say, 75 per cent. in breath and depth, it would be 1 inch thick (or if it varied as the cube, as suggested by Froude, 2 inches thick), whereas in practice $\frac{13}{20}$ inch plating is found to be sufficient. But in comparing vessels so dissimilar in size, an agreement between the scantlings suggested by the elementary girder theory and those found necessary in practice is not to be expected. In a small cargo vessel the scantlings are necessarily much in excess of what would be required were the hull only liable to girder-like stresses (Art. 35). If they were proportionate to the latter (with the same margin of strength as in a large vessel), the apparently large discrepancy between theory and practice would disappear. For instance, in the case of high-speed Channel steamers, which, not carrying cargo, are not liable to all kinds of local stresses and wear and tear, longitudinal strength is the governing requirement, and it is found in practice that it may be satisfied by a very slender structure. In such vessels the thickness of the shell plating is frequently in the simple proportion of about $\frac{1}{8}$ inch for each 100 feet of length. In a vessel 200 feet long $\frac{1}{4}$-inch shell plating might be sufficient; and, taking this as a basis, the $\frac{13}{20}$-inch plating of a 400-feet vessel is not inconsistent with the foregoing theory. In the case of Atlantic liners over 500 feet in length, where longitudinal strength is a paramount consideration, it is found that, to maintain a similar margin of strength, a small increase in length involves additional structural material varying in *weight* practically as the cube of such increase; this, again, is an agreement with theoretical conclusions.[1]

Nevertheless, in deciding the appropriate scantlings for any particular vessel, theory by itself has little useful application. Its conclusions are necessarily vitiated by assumption and the neglect of important influences too subtle and involved for mathematical treatment. The foregoing investigation, for instance, indicated that when the breadth and depth are increased together the thickness of the plating might be reduced in direct proportion. Viewed from a practical standpoint this is evidently absurd, if only from the circumstance that the thinner the plating the smaller is its efficiency per square inch in resisting compressive stress. The larger the area of plating exposed to water pressure and other lateral stresses, the stiffer and stronger it should be. The greater transverse stresses which accompany increased transverse dimensions are provided for, in large part, by greater massiveness in the framework; but as the plating is the medium through which the stresses are conveyed thereto, it should evidently be of suitably proportionate thickness. Lloyd's plating numeral is a sound one practically, for it takes account not only of the vessel's length, but of the total area of the shell. If it accorded strictly with the girder theory (and assumed that the length, breadth, and depth of all vessels bore the same ratio) it would, as just seen, take no cognizance of the vessel's breadth or depth, but only of the length.

[1] See Prof. Elgar's paper, *Trans. Institution of Naval Architects*, 1894.

Art. 43. The **maximum weight of cargo** that a vessel may be called upon to carry should, of course, have a governing influence on the strength required in the hull, for it is upon the displacement or weight of the hull that the intensity of the hogging, sagging, and various transverse stresses in great part depends. For instance, if two similar vessels of equal strength were loaded, the one with a heavy cargo and the other with a light one, it is evident that if the difference in draught or displacement were considerable, the latter would have a much larger margin of strength; if sufficient in the one, it would be unnecessarily large in the other. If employed only for light cargoes, such a vessel could not be regarded as an efficient one for her purpose, for, with lighter scantlings, she might have ample strength, and her first cost would be less; or with the same outlay a larger vessel might be built, having greater stowage room or earning capacity for light, bulky cargoes.

To meet such cases, of vessels of similar dimensions carrying different loads, it has often been suggested that, in place of tabulating the scantlings under dimensions or numerals, it would be better to employ the maximum displacement.[1] But although a **displacement basis** has much to recommend it, its superiority as a substitute for Lloyd's numerals would be very doubtful, for it takes no account of a vessel's relative dimensions, which, as just seen, have a commanding influence on the stresses; also, to obtain the displacement involves a somewhat tedious calculation, whereas to compute the numerals is simplicity itself. Although displacement is not Lloyd's basis for scantlings, it is specially regarded in the general scheme of their rules, for, to suit different trades, different types of vessels are prescribed, and for each one special rules of construction, giving varying degrees of strength.

Art. 44. In **tables of scantlings** a particular size in any one structural part must of necessity serve for a **group of vessels** not all exactly alike in point of size. Thus, for a vessel 200 feet long the proper thickness of shell plating is about $\frac{9}{20}$ inch, and for one 400 feet long $\frac{13}{20}$ inch. Now, between such vessels there might be any number of intermediate sizes, and as there is only a difference of $\frac{4}{20}$ inch between the plating of the largest and of the smallest, the question arises, how to assign an appropriate thickness to all? If, as in Lloyd's rules, $\frac{1}{20}$ inch be taken as the **smallest unit of measurement**, then the multitudinous intermediate vessels might be divided into four groups, or grades, one comprising vessels between 200 and 250 feet, another those between 250 and 300 feet, and so on, all vessels in any one group having the same thickness of shell. If, instead of $\frac{1}{20}$, $\frac{1}{40}$ inch were chosen as the unit of measurement (as is done by the British Corporation), the range in size of the vessels comprised in each group would be reduced, and theoretical perfection more closely approached; if the thickness could be measured in hair-breadths it might be attained. The question is one of practical expediency. In the actual work of checking scantlings there is often difficulty in discerning with accuracy even so comparatively large a variation as $\frac{1}{20}$ inch. In the rolling operations at the steel works, to produce a wide plate of one precise thickness throughout is practically impossible; the marginal parts may be thinner or thicker than the central portion by $\frac{1}{20}$ inch (Art. 569). To require that the structural material of a ship should conform to sizes given in fortieths of an inch would lead to trouble; disputes might arise as to the real thickness. Evidently, therefore, little or no practical good would follow from the adoption of a smaller unit than $\frac{1}{20}$ inch.

[1] See the late Mr. William Denny's paper, "*On Lloyd's numerals*," *Trans. Institution of Naval Architects*, 1877; also two papers by the late Mr. John in the same volume.

When the size of a vessel is such that she just *oversteps a grade* and becomes liable for heavier scantlings, it is sometimes argued that it is unfair that so small an increase in dimensions should necessitate so much greater strength; an extra inch in the length, beam, or depth, for instance, should not really necessitate additional thickness in the shell plating, or, if it did, then the slightly smaller vessel, not having it, could only be regarded as too weak. But it is evident that as a vessel gradually increases in size, by steps, no matter how small, there must arrive a period when some additional thickness in the structural parts becomes necessary. The scantlings, moreover, are fixed, not with theoretical nicety, but more or less empirically; they provide a considerable margin of strength, and so what might appear to be an inconsistency when viewed critically, from the point of view of strength only, is not so in reality.

Lloyd's rules are so schemed that, despite the comparatively large $\frac{1}{20}$ inch unit of measurement, the increase in the strength of hull or weight of structural material involved by slightly increased dimensions is small. In the case, for instance, of two vessels which differed from each other only by one grade, and which, therefore, were not very dissimilar in point of size, it would evidently be quite improper to make the entire shell plating of the larger $\frac{1}{20}$ inch thicker than that of the smaller, for, if $\frac{1}{2}$ inch thick in the latter, the increase would be 10 per cent. Such sudden variations are, of course, avoided. In the case of the shell, the additional thickness required in each grade is not applied throughout, but only to a few of the more important strakes; several grades may be overstepped before a general increase of $\frac{1}{20}$ inch is required. And, moreover, further to avoid any suddenness in the increase of scantlings, different structural parts are placed under different numerals, so that while a slight increase in the vessel's dimensions may entail no extra thickness in, say, the shell, it may necessitate stronger keelsons or thicker deck plating. In this way, variations in the weight or strength of structure may be almost as gradual as variations in dimensions.

Art. 45. Besides Lloyd's Register, there are some eight other classification societies,[1] all of which publish register books and rules of construction; the latter, however, is in most cases a more or less modified copy of Lloyd's rules. Lloyd's Register has seldom stood alone in this country; formerly there was the Liverpool Underwriters' Registry (amalgamated with Lloyd's in 1885); and now there is the recently established British Corporation of Glasgow. Of the foreign societies, the French Bureau Veritas, established in 1828, is the most influential. Throughout this work, Lloyd's rules, which represent or govern practically all merchant ship building, are constantly referred to; but where points of difference, worthy of notice, occur between these and the methods advocated by the Bureau Veritas and British Corporation, they are cited. The rules of the latter societies do not differ essentially from those of Lloyd's; that this should be so is natural, for the latter represent experiental capital, accumulated from the practice, and at the expense of, the entire shipping community; to differ greatly therefrom would mean something novel and untried, and therefore untrustworthy.

The **Bureau Veritas** recognize similar types to those presented in Lloyd's rules. They have a different system of numerals; the scantlings of longitudinal parts are tabulated under the cubic number, *i.e.* the vessel's length multiplied by her breadth and depth; and the transverse, under the

[1] *The British Corporation, Bureau Veritas, Germanischer Lloyd, Nederlandsche Vereeniging van Assuradeuren, Norske Veritas, Record of American and Foreign Shipping, Registro Italiano, Veritas Austro-Ungarico.*

breadth plus the depth. They place a premium on bulkheads, for if sufficient in number to give immunity from foundering should the hull be perforated between them, the circumstance is indicated in the vessel's class; similarly, those vessels are signalized whose bows are strengthened to resist end-on collision, or impact with ice. The tables of scantlings are threefold; one set for steel vessels, another for those of superior iron, and another for those of common iron, the scantlings becoming greater in each case.

The rules of the **British Corporation** present many points of interest and novelty. They only deal with steel and iron vessels, and they have only one class, "B.S.," or "British Standard." They do not recognize different types, such as three-deck, spar-deck, or awning-deck, but a **freeboard is a condition of classification**, and, having presented certain standard scantlings, adherence to which will permit of the minimum freeboard allowed by the Load-line Act, reductions therefrom are admitted subject to a suitably increased freeboard. The scantlings are tabulated on a special system; the basis for different parts being those dimensions of the hull (taken separately) which directly affect the duty of each part. Thus, the thickness of the shell plating and the scantlings of keels and keelsons are decided by the vessel's length only; but, to provide against the greater longitudinal stresses that accompany increased beam, the number of side keelsons and requirements as to deck plating and stringers are regulated by this dimension, the deck material being also governed by the length. The spacing of the frames is regulated by the vessel's depth; it varies gradually from 20 inches in a vessel 8 feet deep, having shell plating $\frac{6}{20}$ inch thick, to 29 inches in one 44 feet deep, having shell plating $\frac{15}{20}$ inch thick; an increase of $\frac{1}{20}$ inch in the thickness permits of the frame-spacing being increased by one inch, provided the general transverse strength is maintained; and if, contrariwise, the plating is made thinner, the frame-spacing must be reduced. The scantlings of the frames and floors are determined by the vessel's breadth; they vary, however, for each breadth, according as the depth of the hull is great or small. They specify a system of bulkhead construction which differs considerably from that generally adopted and as presented in Lloyd's rules; it is similar to that advocated by the Bulkhead Committee (Art. 206). Their tabulated scantlings are regarded as applicable to all vessels whose length does not exceed 14 times the depth, and whose depth is not less than 55 per cent. of the breadth; Lloyd's tables assume a maximum length of 11 depths, but a special table is provided, giving the additions necessary should such proportions be exceeded. They do not require bulkhead liners unless the spacing of the rivets in the bulkhead frame angles is less than 5 diameters, and they differ considerably from Lloyd's rules as regards the distribution and scantlings of the deck plating and deck stringer plates (Art. 150).

CHAPTER V.

Art. 46. In describing the various **modern types of vessels,** it will be instructive to notice the causes which governed the steps of their development. The first steam vessels were designed in much the same fashion as the sailing-ships of that period. They had a flush upper deck, and, in the absence of a second deck, a tier of hold beams. At the bow they had an anchor deck, or low "monkey forecastle," and aft there might be a raised quarter-deck (Fig. 1A, Plate 26). Subsequently it was found necessary to place the machinery openings at a higher level than the upper deck (Art. 219), and so, for this purpose, casings were built, and, to protect these, a bridge deck, enclosed at the ship's side but usually open at the ends. Then, to increase the carrying capacity and improve the vessel's weatherly qualities, the quarter-deck and forecastle were increased in height, to form a poop and top-gallant forecastle (Fig. 1, Plate 26). The largest vessels of that period were about 250 feet by 33 feet by $17\frac{1}{2}$ feet, but later, when greater carrying capacity was desired, they were increased in size by simply adding 7 feet to their height, so as to give an additional deck. To increase the depth only was thought to be advantageous, for at that time the idea prevailed that the dimension of breadth was the one most particularly governing the vessel's resistance, and that to increase it would entail great loss of speed.

With so large an increase in the depth, the hull became very strong as a girder, and as the freeboard was usually high, due to the circumstance that, to maintain sufficient stability, only light goods could be carried in the upper 'tween decks (owing to their small beam, these vessels, if fully loaded with homogeneous cargo, could not remain upright), the total weight carried and stresses endured by the hull were not increased proportionately. Accordingly, Lloyd's Register modified their rules for such vessels, by basing the scantlings on the transverse numeral reduced by 7 feet, which was practically equivalent to discounting half the height of the additional upper 'tween decks. This modification only applied to this type of vessel, *i.e.* to steamers whose depth to the second deck exceeded 17 feet, and which had three decks, or two and a tier of hold beams. This is known as the "**three-deck rule**"; it is still in force, but whereas, formerly, two laid decks was a condition of the 7 feet deduction, the second may now be dispensed with (*i.e.* when not required as a plated deck for structural strength) if the transverse framing be in accordance with an unreduced numeral, and all the reverse frames be extended to the upper deck; otherwise, if a suitable minimum freeboard be maintained, the rule may be applied without modification. Vessels built under this three-deck rule, as also those which, owing to their small depth, are not eligible therefor, are regarded as vessels of full scantlings; they are the strongest type presented in Lloyd's rules. It will be observed that as sailing-ships are not eligible for the three-deck rule, *i.e.* the 7 feet reduction in the numeral, the scantlings of those over 24 feet in depth are in excess of those in steamers.

It was found, as a result of numerous losses, that vessels of the above narrow, deep model were dangerous,[1] and as with greater knowledge it became apparent that breadth was not disadvantageous as regards speed, the proportions of vessels gradually improved.[2] As now proportioned, with a depth between 50 and 60 per cent. of the breadth, in place of 70, the question of stability has little influence in limiting the depth of loading. Vessels built on the three-deck rule are suited for the carriage of heavy, dead-weight cargoes,[3] for, being built to Lloyd's maximum scantlings, they are so strong that, though loaded to the deepest draught (which, of course, is limited to what will leave a freeboard compatible with weatherly qualities), the hull will suffer no undue stress.

Art. 47. Later, as over-sea trades became more specialized, and the desire grew to employ in each service vessels specially adapted thereto, a new type, known as the "**spar-deck,**" was introduced. The primary purpose of these vessels was the conveyance of passengers, the upper 'tween decks being appropriated for their use, to the exclusion of cargo. Carrying so little weight, and floating with a high freeboard, a lighter structure throughout was admissible, and, accordingly, Lloyd's Register modified their rules by measuring the numeral to the second deck. A specially light construction was allowed for the upper 'tween-deck part of the hull (thin plating, supported only by alternate frames), conditional, however, to no cargo being carried above the second deck; and, to limit the loading, it was recommended that the freeboard from the second deck should not be less than 3 inches for each foot of hold depth below the same. Subsequently, the occasional necessity to carry cargo in the upper 'tween decks, and thus to overload the hull, led to the scantlings of this part being increased; the top-side plating was thickened slightly, and the framing here made of ordinary strength. This type of vessel is still known as a "spar-decker." Being of rather lighter scantlings than a "three-decker," it is especially suited for the carriage of a lighter and bulkier class of goods, a full cargo of which will leave the ship with a somewhat higher freeboard. It is also suited for passenger vessels, because a high freeboard is essential for the comfort of the passengers, and, not being loaded heavily, the hull may be amply strong—unless, of course, it be a large Atlantic liner, in which class of vessel the heaviest scantlings are desirable. Lloyd's spar-deck rule only applies to vessels whose depth exceeds 17 feet to the second deck, for, if less deep, the light upper 'tween-deck structure would represent so large a portion of the hull as to affect prejudicially the general strength. As in the case of three-deck vessels, Lloyd's rules now permit of spar-deckers having only a tier of beams for the lower deck, a suitable increase being made in the frames. And many modern vessels of this type are built with rather heavier scantlings, so that, as in the case of three-deck vessels, they may load to the deepest draught allowed by the Load-line Act.

Art. 48. To take the place of the original spar-deck vessel, *i.e.* one having a very light upper 'tween deck, the **awning-deck type** was introduced (Fig. 5, Plate 26). The primary purpose of this type of vessel was the conveyance of natives from port to port in the East, for whose comfort large ventilating

[1] See Martell's paper, *Trans. Institution of Naval Architects*, 1880, "*On the causes of unseaworthiness in merchant steamers.*"

[2] See Froude's paper, "*On the comparative resistance of long ships of several types,*" *Trans. Institution of Naval Architects*, 1876.

[3] A "*dead-weight cargo*" is one which occupies, in proportion to its weight, so little space, that the amount carried is only limited by the vessel's displacement or the depth to which the hull may be immersed; if so light and bulky that the amount carried is limited by the vessel's internal capacity, it is termed a "*measurement cargo.*"

openings were pierced in the top-side plating. Subsequently, as in the previous case, owners often found it desirable to carry cargo in the upper 'tween decks, which led to the structure being enclosed and strengthened, as in the modern awning-deck vessel. The main difference between an awning-deck and a spar-deck vessel is that the former has more slender upper works; the top-side plating is thinner, the 'tween-deck frames have no reverse bars, and the awning deck and its beams are lighter. The hull proper may be regarded as limited to the portion below the second deck; here it is of full scantlings, the numerals and proportions being taken to this deck. The portion above may be regarded as a mere superstructure, to increase the vessel's capacity for light goods, passengers, or cattle. It is not intended that it shall contribute a full measure of useful strength to the hull, and unless specially designed, it is disregarded in question of strength. To load such a vessel deeply in the water, as in one of full scantlings, would be inadmissible, for in heavy weather the structure might be seriously strained. To preclude this danger (one readily incurred, because the upper or awning deck, being well out of the water, would give an appearance of safe loading), Lloyd's Register at one time required that hinged freeing ports should be cut in the side above the second deck, for, not being watertight, they had the desired effect of limiting the depth of loading to some distance below this deck. Latterly, however, as these were sometimes found to be closed tight, the maintenance of a minimum freeboard was made a condition of classification, a diamond-shaped freeboard mark being painted on the vessel's side. In the case of full-scantlinged, three-deck, and spar-deck vessels, Lloyd's rules do not specify a freeboard as a condition of class; but, as noticed later, all British vessels are now required (by the Merchant Shipping Act of 1890) to conform to an approved minimum freeboard.

Art. 49. A **shade or shelter deck**, as fitted in passenger vessels which trade in the tropics, is merely a flying deck or permanent awning, supported at the vessel's sides by an extension of the stanchions of an open rail; and it may be fitted only locally, or all fore and aft. Such a deck is better described as a "shade deck." A shelter deck, as now commonly adopted in large vessels, is a superstructure extending continuously all fore and aft (see Fig. 7, Plate 20; Fig. 6, Plate 26, and Plate 110); it is usually of substantial construction, so as to confer useful longitudinal strength on the hull. The peculiar feature of such a superstructure is that the 'tween-deck space it encloses is not included in the vessel's register tonnage, this omission being allowed by the existing tonnage laws, on the simple condition that somewhere in the deck an opening is made, with no *permanent means* of closing it, and that no part of the 'tween deck space is partitioned off or enclosed in a permanent manner. The necessary opening (generally referred to as the "tonnage opening") may be formed by one of the hatchways, usually the aftermost, which may or may not have coamings; formerly coamings were not provided, but now they generally are, these being permitted by the Board of Trade, if no permanent means are provided of closing the opening with hatches and tarpaulins, as in an ordinary hatchway. In other cases a small opening or special hatchway is provided, about four feet long, and half the beam of the ship (at that part) in breadth.

The shelter-deck type of vessel originated in the **Atlantic cattle trade.** In the earlier vessels engaged in this trade the cattle on the upper deck were only partially protected by a rough, temporary, shed-like erection of deals, which was sometimes washed away. Later, greater security and comfort for the cattle were secured by building a light, permanent

superstructure, or shelter deck, having breaks at one or two places (over which a temporary deck could be laid), with large gangway doors in the side for the convenient loading of cattle and cargo. As now constructed, the shelter-deck is usually a substantial, continuous superstructure, having two or three small doors in the side for loading cattle (Fig. 4, Plate 60). All the frames are carried up, and web frames introduced or some of the reverse frames carried up to give the required transverse strength against racking or swaying tendencies, which, in the absence of transverse bulkheads, might be pronounced; and, in order to afford useful longitudinal strength to the hull, the deck is usually plated for half, or full length, and the side plating thickened beyond that necessary for a mere superstructure, a suitable reduction being made in the thickness of the top-side plating of the hull below. Having the great advantage of providing a large cargo space on a small registered tonnage, shelter-deck superstructures are now extensively adopted in both cargo and passenger vessels, the latter having usually a 'midship bridge-house (superposed on the shelter deck) for the accommodation of the passengers (Fig. 7, Plate 20).

Art. 50. The **well-deck type** of vessel (Fig. 2, Plate 20, and Figs. 2 and 3, Plate 26) originated with the desire to increase the capacity of the after hold; for, with the machinery situated amidships, the greater fineness of the after lines, and the space occupied by the shaft tunnel made it so much smaller than the fore hold that when both were full of homogeneous cargo, such as coal or grain, the vessel trimmed by the bow. Accordingly, to increase the capacity of the after hold, the expedient was adopted of adding to its depth, by raising the upper deck (or *quarter-deck*, as the after part of the upper deck was formerly termed) some 3 or 4 feet higher than elsewhere. At first the bridge-house (at the after end of which the raised quarter-deck terminates), although enclosed at the sides to protect the machinery casing, was left open at the ends; but subsequently, to increase the weatherly qualities and safety of the ship, bulkheads were fitted at either end, with or without doorways. Later, the bridge was extended in length forward, to provide additional space for light cargo, or for the cabins, formerly located aft, in a short poop or a further raised quarter-deck on the quarter-deck proper (Fig. 2, Plate 26).

The forward extension of the bridge-house reduced the space between it and the end of the forecastle, which, forming with the bulwarks practically a square pit in the weather deck, and in heavy weather being constantly full of water, was appropriately termed the "*well*." In some of the later vessels of this type the well is reduced to very small dimensions, having a length perhaps only one-tenth that of the vessel. It is an objectionable feature; for, as it forms a deep cleft in an otherwise continuous superstructure, it sacrifices possibilities of longitudinal strength; but as these vessels are of moderate size, and as the well is remote from 'midships, this is usually a minor consideration. Also, the front bulkhead of the bridge forms a target for the waves, and with the upper deck in the well constantly inundated, the hatchway, always placed here, is undesirably exposed to sea pressure. In some of the latest vessels of this type, these objections were met by suppressing the well, by joining the bridge and forecastle decks (Fig. 5, Plate 20, and Fig. 4, Plate 26). Such vessels are termed "*partial awning deckers*." In some few cases, in place of covering in the well, the curious plan was adopted of raising the upper deck within its boundary by some four feet; the advantage being the greater height of the upper deck above the sea level, and the reduced depth, or capacity of the well for sea water. Such vessels are termed "*raised fore-deckers*."

It should be observed that when the well is long it is even more

objectionable than when short, for it may hold a larger volume of water, and the bridge bulkhead, being less protected by the forecastle, is liable to more severe bombardment by the waves; in many cases this bulkhead has been damaged or stove in, and so special care is now taken in its construction (Art. 211). When the well is fairly long it serves a useful purpose, for it results in a dead-weight carrying vessel of small tonnage, having ample cargo capacity in the after holds. When it becomes very short its presence is anomalous; its shortness permits of a smaller freeboard, but a still smaller one and a better ship is secured by its complete suppression.

Much has been written of the peculiar merits of the well decker, which, until comparatively recently, was the favourite type of tramp cargo vessel.[1] Structurally the design is not efficient, because of the serious discontinuity of so much important fore-and-aft material. At the junction of bridge and quarter-deck, nearly amidships, all of the upper-deck plating is severed, and at the same spot the deck and side plating of the bridge terminates (see Plate 14). To restore the strength, numerous local reinforcements are required, such as scarphing the ends of the severed upper deck, doubling the shell plating, etc., and, while adding weight to the hull, such additional structural material does not contribute to the general strength, but only makes good, in a clumsy fashion, a weakness due to inefficient design. The comparative freedom from straining which these vessels enjoy, is due to their moderate dimensions, for when so large as to require a second plated deck, the well-deck design is inapplicable. In the largest vessels of this class, however, weakness has frequently been shown at the break of the quarter-deck, either by fractured plates or started joints; in such, therefore, the greatest care must be observed to secure sufficient strength. Lloyd's rules treat a well-deck vessel as one of ordinary type, but specify in detail the various compensations required to make good the strength prejudiced by the discontinuity in the upper-deck material, and to secure sufficient transverse strength in way of the abnormally deep after-hold (Art. 160).

Art. 51. The **whale-back type** of vessel is practically confined to the American lakes.[2] As the name implies, the deck and side are rounded into one another, with an easy curve; the hull has no sheer, and has a shelving or "spoon" bow. For their particular purpose they are found to be suitable and economical, because they are cheap to construct, and, having numerous hatchways (usually composed merely of portable plates bolted on the deck), they may be expeditiously loaded, and, heavily, for they appear to navigate with safety with a very small volume of spare buoyancy. For ocean voyages, however, they have been found quite unsuitable.

The **turret-deck type**,[3] recently introduced, may be regarded as a development of the American whale-back; the only resemblance, however, is in the rounded gunwale and the absence of sheer; under water the hull is of normal form (Plate 111). Its peculiarity lies in the fore-and-aft superstructure, which resembles a continuous high-coaminged hatchway, decked over, however, except in way of the hatchway openings; it is termed the "turret deck"; the low-lying deck on either side, on which, at sea, there is no traffic, being termed the "harbour deck." Several

[1] For a study of these vessels see M. Sivewright's paper, *Trans. North-East Coast Institution of Engineers and Shipbuilders*, 1888–89.

[2] For an account of these vessels, see Mr. Goodall's paper, *Trans. Institution of Naval Architects*, 1892.

[3] See Mr. S. O. Kendall's paper, *Trans. North-East Coast Institution of Engineers and Shipbuilders*, 1894–95; and *Engineering*, May 26, 1893.

advantages are claimed for the design, particularly its suitability for carrying bulk grain. As this cargo demands certain structural provisions, it will be well to notice its peculiarities.[1]

Art. 52. In loading **grain** it is endeavoured, as far as practicable, to fill completely all spaces in the holds, for if this be not done, the whole mass, flowing almost like water, **may shift** with the rolling and jerking of the vessel, and, settling down on one side, cause a dangerous list; many vessels have been lost from this cause. To ensure, in an ordinary vessel, that all spaces are filled is a difficult matter, for when the grain is poured in through a few isolated hatchways, it will not flow everywhere out to the sides and rise up under the gunwale; it must be trimmed by hand. If there is a 'tween deck it is usually pierced (at the sides, where remote from the hatchways) with *trimming holes*, two or three feet square, through which the grain may be poured so as to bring it close up to the deck (Fig. 2, Plate 27). But even when the hold is filled quite full, the grain tends to subside or settle, so that at the end of a voyage its surface may be one or two feet lower than at the start; in which case the resulting vacant spaces, giving play, as it were, permit the whole mass to flow to one side. To mitigate the dangerous heeling effect of such shifting, all vessels which carry grain in bulk must be provided with **shifting boards**, *i.e.* a fore-and-aft centre-line partition in the holds. Usually it is formed of portable boards, but sometimes it is a permanent iron bulkhead (Art. 148). To provide against the settling of the grain, it is usual, in two-deck vessels, to construct *feeders*, or grain reservoirs. These are simply wooden or plated trunkways built around the various hatchways between the upper and second decks; they are filled with grain, which falls automatically to fill any vacant spaces that may form below. In ordinary one-deck vessels feeders cannot be provided; in these, therefore, it is not attempted to fill the holds quite full of loose grain, but a space is left, and shifting provided against by covering the surface of the grain with matting and boards, and laying upon these bags of grain. For a similar reason loose grain is not carried in upper 'tween-deck spaces. Turret-deck vessels, owing to their rounded gunwales and numerous hatchways, may be filled quite full of grain without any hand trimming; and, despite their having only one deck, they carry it with safety, for the capacious central trunkway forms a most efficient feeder.

Art. 53. Structurally, the **turret-deck design** has certain advantages; in an ordinary vessel, owing to the sheer, the shallowest part of the hull is amidships, just where, for longitudinal strength, it should be deepest; in a turret-deck vessel the depth is uniform, for there is no sheer; as against this, however, a larger freeboard is required for weatherly qualities. In an ordinary vessel the deck plating is thin, and does not contribute its full quota of longitudinal strength; in a turret-deck vessel it is thick like the sides, and owing to its double curvature is naturally stiff and capable under both tension and compression. Each side of the continuous superstructure, if regarded as representing the sheer strake of an ordinary vessel, is remote from the neutral axis, and so in this respect is well placed for longitudinal strength; but as there is no rigid web uniting it with the bottom of the hull, it is doubtful if it can be regarded as possessing the full value of a sheer strake. If the depth of the hull be reckoned to the top of the superstructure or turret deck, then, owing to the corrugations formed by the gunwale, its transverse strength is naturally good; an ordinary vessel, with

[1] For papers on this subject, see those of Professor Elgar, and the late Professor Jenkins, in the *Trans. Institution of Naval Architects*, 1887; Martell's, 1880, and Mr. Little's, 1896.

a flat side of the same depth, would require a second deck, or special side-stringers and extra strong framing. In ordinary vessels, to stiffen the deck and distribute the supporting effect of the pillars, fore-and-aft stringers are fitted under the beams; in a turret-deck vessel, the deep sides of the superstructure afford such excellent vertical rigidity to the deck that only a few widely spaced, strong built pillars may suffice—a circumstance greatly facilitating the stowage of packages in the hold (Plate 111). In some of these vessels the machinery is placed at the stern, and in their construction many simplifications and novelties are introduced, tending to reduce the weight and the first cost of the hull. Having a small tonnage, and, in proportion to their size, a light hull, they are particularly suited for dead-weight cargoes; and, having special facilities for loading and discharging, they are economical in working expenses. They appear to behave well at sea, and though waves may wash over the low-lying side portions of the deck, it is said that the high turret deck remains fairly dry, and offers a safe working platform.

The **trunk-deck type** of steamer[1] is similar to the turret-deck one just described, in that there is a continuous central erection on the upper deck, open to the hold; in this case, however, the gunwale is not rounded (Plate 112). Trunk-deck vessels are practically of ordinary design, except that they have what might be described as a continuous hatchway, having coamings about 7 feet high, decked over on the top. Like turret-deck vessels they are suitable for carrying grain in bulk, the trunk forming an excellent feeder. The design is also employed, in some cases, for steamers which carry oil in bulk.

Art. 54. Vessels which carry **petroleum in bulk** are of special design.[2] Formerly this oil was shipped in barrels or metal cases, an inconvenient method, owing to the cost of the barrels and the labour and time required to load and discharge, also because so much hold space was lost through broken stowage that the vessel's full carrying power was not available. The first innovation was the building within the hull of permanent tanks, the oil being loaded and discharged therefrom by pumping. Later the tanks were made of large size, the containing walls forming an inner skin of the hull. This was found to be unsuitable, for it was a difficult matter to make the inner walls oil-tight, and the leakage into the confined spaces between the two walls caused dangerous accumulations of explosive gas. Subsequently the present simple method was adopted of carrying the oil in the vessel's holds, these being made of small size, by means of numerous bulkheads, so that each one forms a separate oil-tight tank (Plate 26). In the structural design of oil vessels there are three matters requiring special attention—strength in the hull; safety from explosion, due to leakage and consequent accumulations of oil-gas; and stability. A fluid cargo is a very trying one; it does not, like a solid one, lie inert upon the bottom framework, but presses in all directions, not upon the framework, but on the vessel's plating; it possesses, moreover, should it move about, disruptive powers which may prove disastrous.

When the vessel is at rest, the intensity of the pressure tending to burst the containing walls of the **oil tanks** (the bulkheads, vessel's sides, and the deck forming the tank-top) depends on the depth of the oil; when at sea,

[1] A description of these vessels will be found in a paper by Mr. W. Hok, in the *Trans. Institution of Naval Architects*, 1898.

[2] For instructive papers on oil-ships, see the *Trans. Institution of Naval Architects;* Martell, 1887 and 1894; Mr. Eldridge, 1892; Mr. Hok, 1895. The *Trans. Institution of Engineers and Shipbuilders in Scotland*, Jenkins, 1888–89. The *Trans. North-East Coast Institution of Engineers and Shipbuilders*, Mr. Kendal, 1892–93.

however, this pressure may be enormously increased by lively motion of the vessel. So long as the oil is confined, *i.e.* entirely fills the tanks, its pressure, though intense, is of a statical or steady character, readily provided against. Should a tank not be quite full, however, the oil, being free to move, becomes a dangerous live-load; when put in fore-and-aft and transverse motion by the pitching and rolling of the vessel, the battering force exerted by so large a mass, dashing from bulkhead to bulkhead and side to side, may be almost irresistible. To prevent, therefore, such a dangerous occurrence, provision is made for keeping the tanks at all times quite full, by constructing over each one an *expansion trunk* (Fig. 11, Plate 26), *i.e.* a casing or vertical extension of the tank, which, being partly filled with oil, acts as a reservoir or feeder. All fluids expand and contract with heat and cold (oil does so more than water), so that, without a reservoir, any increase of temperature occurring during the voyage would result either in the bursting of the tank or in a loss of oil; and a fall in temperature would so lower its surface as to give freedom of motion, with the above result. Of course, as the expansion trunks are small, freedom of the oil within them is unimportant. Formerly they were made of small size, one for each tank; now they are usually built as a continuous central casing. By this arrangement the strength of the deck and of the structure generally is greatly improved; the large openings permit of better ventilation when the tanks are empty, and of cargoes other than oil being more readily stowed.

In the earlier days of bulk-oil vessels, the **disruptive power of free fluid in a tank** was not sufficiently realized, and, as a consequence, the structure often suffered serious damage. When the vessel is loaded with oil there is little danger, for the tanks are then quite full, and the bulkheads, having fluid pressure on both sides, suffer little stress, excepting the terminal bulkheads at bow and stern, which, however, being double, have naturally great strength. The most trying condition is usually experienced during the vessel's return voyage, empty, to the oil-loading port, when a few of the oil tanks are filled with water for ballasting purposes. If they were filled before putting to sea no evil would result, but not infrequently, with a view to making a fast passage, a vessel may start light, and, meeting heavy weather, to improve the weatherly qualities, additional tanks may be run up, and, as she may then be in lively motion, with serious consequences during the filling. When a tank is, say, half filled, the straining effect of the water, dashing from bulkhead to bulkhead and side to side, may be very excessive, more especially in the case of the bulkheads separating an empty from a full tank, where the pressure is all on one side. To subject a tank to such an ordeal is, of course, quite improper, but as the contingency is always probable, it must be provided against as far as practicable, by making the tanks small and the structure strong. A reduction in the size of a tank at once diminishes the disruptive power of free fluid within it; if it were a mere cell, the fluid, having little weight and no scope for action, could do no harm. The larger the fluid mass, and the longer the tank or distance through which it may move and acquire momentum, the more irresistible is its disruptive power. The tanks in any particular vessel might be made small by introducing numerous transverse divisional bulkheads, the transverse strength of the hull benefiting adventitiously by the support; but though small in volume, their athwartship dimension, in a broad ship, would be too great. In practice, therefore, not only are they made short fore and aft, but each tank is divided into two by a longitudinal central bulkhead (Figs. 10 and 11, Plate 26).

A longitudinal bulkhead is an essential feature of an oil ship. It is useful in many ways, for it not only reduces the transverse size of the

tanks, minimizing the dangerous consequences of free side movement in the fluid, but strengthens the transverse bulkheads, and reduces in a very effective manner the dangerous heeling effects to which these vessels may be exposed. If a tank extended from side to side, then during the filling or discharging operations, when only partially filled, the fluid, flowing to one side, might, if the ship were in unstable trim, give her a serious list, a circumstance greatly emphasized should several tanks be filled or emptied simultaneously. The comparative heeling effects of fluid in a tank, with and without a central division, is depicted in Figs. 16 and 17, Plate 21. In Fig. 16 the inclining tendency due to the wedge-shaped mass of fluid A having shifted over to B, is measured by its volume multiplied by the distance AB, through which its centre of gravity has moved. In Fig. 17 there are two wedges, whose combined area or volume is only half that of the single one in Fig. 16; and as the distance through which they have moved is also only half, their movement or heeling effect is one-quarter of that in Fig. 16 (assuming the same angle of heel); that is to say, the central division, while halving the size of the tank, reduces the heeling tendency of free fluid to one-quarter (assuming the vessel to be heeled over to the same extent in either case); to produce the same effect by reducing the length dimension of the tank would require that it should be divided into four.

A longitudinal bulkhead also serves a useful purpose in supporting the transverse ones. In its absence each of these would present so large an area to fluid pressure, dynamical and statical, as to require a very massive construction. When supported on either side by a fore-and-aft division, each bulkhead becomes practically two of half area; horizontal stiffeners become eight times as stiff, twice as strong, and liable only to half the bending pressure. Also, extending from keel to deck, a continuous fore-and-aft bulkhead adds great longitudinal strength and stiffness to the hull. It is strongly constructed like the transverse ones (Figs. 10 and 11, Plate 26), for although it need not at any time be exposed to large one-sided pressures, it is liable to the concussive effects just noticed. In the earlier vessels it was not strongly built, and in some cases it burst away. It may or may not be quite oil-tight; the special care required to make it perfectly so is not usually observed, for, unlike the transverse divisions, it is never required that a tank on one side of it shall remain permanently full, and on the other quite empty. Usually there is a valve at the bottom, so that, when required, the port and starboard tanks may be made one.

The **workmanship** and arrangement of the various **structural details of oil vessels** require special attention. This was not at first sufficiently realized; the scantlings were the same as those adopted in ordinary vessels, and it was anticipated that, with so many additional supporting bulkheads, the transverse strength would be ample. But although the general strength of the hull was sufficient, the local straining effect of the fluid cargo was found to be so exceptionally severe that numerous substantial reinforcements had to be made. The experience thus gained, although unsatisfactory to those financially concerned, has proved valuable to naval architects, for, of course, more may be learned from a single failure than from any number of successes. The various local weaknesses observable in the first oil vessels provided useful lessons in showing the weak spots and the straining tendencies prevailing, not only in oil ships, but in similar structural parts of ordinary vessels.

As now constructed, oil-vessels are perfectly strong and able to withstand all but very improper treatment. The scantlings of the frames and plating are much the same as those adopted in ordinary vessels,

but in the bulkheads and other parts much greater strength is provided. The transverse strength is naturally superior, on account of the numerous transverse bulkheads, placed usually at intervals of 25 to 35 feet; so great, however, are the local panting and racking effects of a fluid cargo, that it is found necessary to place between each of these two or three powerful web frames (Figs. 10 and 11, Plate 26). In some of the earlier vessels it was attempted to support the sides by hold beams, but owing to the local nature of their holding effect they were found to be very inferior to web frames; the rivets in the vicinity of the beam ends strained and slackened, and local panting movement of the side was insufficiently checked. The parts requiring particular attention are the bracket plates connecting the side stringers to the bulkheads and those holding the ends of the bulkhead stiffeners. At first these were made small, as in ordinary vessels, but they were found to be inadequate, the rivets could not hold them, and so, to increase the connection, they were made about twice the usual size.

A fluid cargo is one particularly **trying on the riveting**, and in oil ships, therefore, this requires special attention. Whether it be steady or concussive, the bursting pressure on the containing walls of a tank takes effect only on the plating, and as it is the framework that gives the resistance, all pressures have to be conveyed thereto through the rivets, placing them in tensional stress, tending to pull off their heads and points, elongate and slacken them. It is found necessary, therefore, to increase the number of rivets, by a closer spacing throughout. This is also necessary for the sake of oil-tightness (Art. 295). Further, care must be taken that all rivets are perfectly sound; any lack of coincidence in the rivet holes, although perhaps not appreciably affecting the soundness or watertightness of the rivets in ordinary cases, is inadmissible in oil-tight work. To ensure sound rivets, three-ply joints are avoided wherever practicable (Art. 327).

In the design of an **oil vessel** the avoidance of **risk of explosion** is an important matter. Petroleum itself is harmless, a light plunged therein being immediately extinguished; it is the vapour which it emits that is dangerous; if mixed with air in suitable proportions it will explode on coming in contact with a naked light. The most dangerous period is when an oil tank has just been emptied, for the vapour which arises from the large internal surface, damp with oil, if not at once removed or enormously diluted with air, may form a highly explosive mixture. Formerly this circumstance was not realized, workmen entered newly emptied and ill-ventilated oil tanks with naked lights, and many lives were lost. Now, of course, precautions are observed; ventilation of the most approved kind is employed, and naked lights prohibited (Art. 449).

During the conveyance of an oil cargo, explosion can only occur as a result of leakage. The only places into which oil may leak are the 'tween-deck spaces above the oil compartments and the holds at the bow and stern. The greatest care is therefore observed to secure oil-tightness in the parts of the tanks bounding these spaces—the deck forming the crown of the tank, the expansion trunks, and the terminal bulkheads. In the case of the terminal bulkheads, absolute freedom from leakage is imperative, more particularly in the after one, which divides the oil tanks from the boiler room. Should even a small quantity of oil find its way into this space, abounding in fire and heat, the explosive gases evaporating therefrom would be a serious danger; in some of the earlier vessels disasters occurred from this cause. To provide against it, it is the invariable practice to form a **cofferdam** by building **duplicate bulkheads**, with a space between, usually 4 feet in width. This affords

perfect security, for should oil leak through the first bulkhead, it would have a second to pass before entering the boiler room; and as, with small leakage, there would be no depth or pressure of oil in the cofferdam, the chance of its passing the second is remote. To provide against even this chance, it is a common practice to fill the space betwixt the bulkheads with water, for then any oil leaking through would float harmlessly to the surface. Similar cofferdam bulkheads are built between the oil tanks and the forward hold.

Oil vessels may be of three-deck, spar-deck, or awning-deck type, and in some cases the trunk-deck system of construction is adopted. They have usually two decks, the second forming the tank-top, and the upper one sheltering it from the sun—a point sometimes urged as important. The 'tween-deck space permits of lofty, well-protected expansion trunks, and provides useful space for coal bunkers or for cargo other than oil. In these vessels some top weight is desirable, for with all tanks full they are usually so stiff as to be uneasy at sea, the structure suffering in consequence (Art. 173). The machinery space is practically always at the stern; to place it amidships is inconvenient and costly, for it involves additional cofferdam bulkheads, and as the shaft tunnel passes through the after oil tanks, it forms an element of danger from oil leakage. A few sailing-ships have been built for the conveyance of oil in bulk. The majority are small, and carry the oil right up to the upper deck; a few, however, are of large size, having, as in steamers, a 'tween-deck space above the oil. Such vessels are undesirably stiff at sea, the compact, low-lying cargo causing too great a metacentric height.

CHAPTER VI.

Art. 55. The question of **freeboard** has always been a prominent one. The fact that many losses have occurred through overloading, whether from ignorance or with the knowledge of those responsible, is one of public interest.[1] Prior to 1890 owners and captains were practically free to load their vessels as deeply as they pleased, except, of course, they were clearly unseaworthy, when they were liable to be detained by the Board-of-Trade officials. In 1876, to check in some measure the prevailing danger to life and property, it was enacted in Parliament that all vessels should have a freeboard mark painted on the side, referred to usually as the "Plimsoll-mark;" but as the choice of its position was the owner's, its presence was not always a guarantee of safe loading. A rough rule formerly used for estimating the freeboard was to make it a fraction of the vessel's depth; from $1\frac{1}{4}$ to 4 inches for each foot in the depth of hold, according as the vessel was of the smallest or largest size. At one time *Lloyd's Underwriters' Association* recommended a minimum freeboard of 3 inches per foot of hold, this being long known as "Lloyd's Rule." As this method of computation takes no account of the vessel's proportions, or form above and below water, it was not at all satisfactory; while giving an appropriate freeboard in one vessel, it might give quite the reverse in another.

With a view to assisting shipowners in estimating appropriate freeboards for their vessels, and to assigning with fairness those for awning-deck vessels (required as a condition of classification), Lloyd's Register issued in 1882 tables of freeboard. These were based on the general average of the best current loading practice, ascertained by wide investigation and consultation with shipowners and others, and took account, comprehensively, of all the governing elements in the structural design and form of the hull. They were largely made use of by shipowners, for besides giving them comfortable assurance as to the safety of their ships, it was often to their real advantage, by permitting a deeper loading than they formerly thought compatible with safety. With a view to rendering compulsory an adherence to a minimum freeboard, the Board of Trade appointed, in 1883, the **Load-line Committee** (an authoritative body in which was represented the Board of Trade, the Admiralty, classification societies, naval architects, shipbuilders, and shipowners), to investigate and ascertain whether or not it were practicable and desirable to frame fixed rules for freeboard, which, while preventing dangerous overloading, would not unduly interfere with trade. After extensive research it was found to be both feasible and desirable, and, in collaboration with Lloyd's Register, tables of freeboard were drawn up, which, practically, were those

[1] An interesting account of the freeboard question will be found in Mr. Martell's Mansion House paper of 16th December, 1886, "*Review of the History of the Load-line Question;*" and his papers in the *Trans. Institution of Naval Architects*, 1874 and 1882. Also see the *Report of the Load-line Committee*, and subsequent explanatory pamphlets.

just mentioned as already adopted by that body. They were accepted by the Board of Trade and embodied in the *Merchant Shipping Act of* 1890, and are now compulsory for all British vessels—merchant vessels over 80 tons. The freeboard mark is a disc permanently cut on the vessel's side (Fig. 8, Plate 8); this represents the maximum depth of loading for summer voyages; for summer voyages in the peaceful Indian Ocean a rather less freeboard suffices; for winter seasons a rather greater is required, and (excepting large steamers, other than well-deckers, over 330 feet in length) for winter in the North Atlantic, where storms of the greatest severity are encountered, still greater. These exceptional conditions of loading are indicated by supplementary marks alongside the disc.

Art. 56. As the question of **freeboard** is intimately connected with that of structural strength and design, it will be instructive to notice the **principles involved** in its computation. Freeboard, it may be premised, is the height of the upper deck above water, taken amidships at the gunwale. In computing it there are two governing elements—the maintenance of weatherly qualities, and the avoidance of so heavy a loading as might overstrain the structure of the hull. These are quite distinct. A vessel might be so strongly built that even when loaded to the gunwale the main structure would not be overtaxed. In such the freeboard would be governed only by what was necessary for weatherly qualities, *i.e.* an easy behaviour of the ship at sea, and a deck so high above the water as not to be readily swept by the waves. If it were too small, the vessel would not rise smartly to the waves, and if, as a consequence, masses of water should sweep the low-lying deck, they might damage or carry away deck gear, ventilators, hatch-covers, casings, companions, etc., and, with the deck momentarily submerged, water might find access below (Art. 219). In passenger vessels the comfort of the passengers demands a dry deck, and to ensure this it must be well above the water, the freeboard, therefore, being greater than might be necessary for mere weatherly qualities or the safety of the ship.

The tendency to ship water is dependent on the **reserve buoyancy**, and on the design and height of the above-water hull. Reserve buoyancy may be defined as the *lifting power*, and is measured by the volume of the hull above the load-line. A ship without sheer, loaded down to the gunwale, would have no reserve buoyancy, and so would not lift at all to the waves; she would be in the condition of a submarine boat, and would—if the upper deck were watertight—remain stationary if completely submerged. The important quality of *liveliness*, *i.e.* the vessel's capabilities in lifting promptly to the waves, is measured not by the mere volume of the reserve buoyancy, but by the proportion which it bears to the vessel's weight or displacement. It is usually stated as a percentage of the whole volume of the hull; if less than a certain amount, depending on the rate of advance of the waves, the hull would not rise quickly enough to ride over them. A vessel's *wave-riding qualities* are greatly dependent on the fore-and-aft distribution of her reserve buoyancy; it is the bow and stern which first encounter advancing waves, and so, to lift promptly and avoid shipping water, it is here that buoyant power is most effective. A flush-deck vessel, without sheer, would, unless the freeboard or reserve buoyancy were large, have inferior weatherly qualities to one having a good sheer.

Art. 57. The following is the general principle on which the **freeboard tables** are arranged. Vessels are classed under **four divisions**—steamers of full scantlings, spar-deck vessels, awning-deck vessels, and sailing-ships. Reserve buoyancy is, of course, the basis on which the freeboards are estimated. It is tabulated as a percentage (of the total volume of the hull

below the upper deck) for vessels of varying size (as measured by their depth) in each class. The strength of the hull is assumed equal to that prevailing in vessels of Lloyd's **100A**, three-deck class (as constructed in accordance with the rules current in 1885); if less, the tabulated freeboards are increased. The reserve buoyancy required (for vessels of the first division) varies from about 20 per cent. in a small vessel 6 feet deep, giving about 9 inches of freeboard, to 35 per cent. in a large one 35 feet deep, giving about 10 feet of freeboard. It is evident that the freeboard of a large vessel must be much greater in proportion to her depth than that of a small one, for the latter may rise to each individual wave, and, having a smaller fore-and-aft moment of inertia, may do so in a fashion so lively as to preserve a dry deck; but a large vessel may embrace in her length several waves, which, having individually little lifting-power, may surge high up upon her sides. The length of the hull is an important feature in regulating the freeboard; if, while preserving the same percentage of reserve buoyancy, the length were conceived to be indefinitely increased, the hull would not rise at all to the waves; to preserve a dry deck the freeboard would have to equal them in height (or, rather, half their height, from trough to crest). The familiar case of a floating log or spar suggests itself: when lying end-on to small waves, each portion as a wave passes becomes completely submerged; a small length cut from the same spar would float with the same freeboard or reserve buoyancy, but would ride over each wave. The tabulated freeboards assume a standard length—for steamers twelve times the depth, and for ships ten times; if greater or less, the freeboards are increased or diminished.

To simplify the **application of the tables**, not only is the percentage of reserve buoyancy required for each size of vessel given, but also the freeboards which give approximately this percentage. This presentation of the double data is feasible, because, owing to the general similarity in the form of all vessels, a horizontal plane or waterline placed at the same proportionate height will divide the hull into two volumes, bearing to one another, in each case, practically the same proportion. This similarity of relation only holds when the hulls are equally full or fine, for, of course, if one vessel had rectangular sections throughout and another triangular, a freeboard of half the depth, while giving in the one 50 per cent. of reserve buoyancy, would give in the other 75 per cent. Such discrepancies are provided for, however, by tabulating separate freeboards for vessels of varying degrees of fulness. The tabulated freeboards assume a certain standard mean sheer (which in inches equals the vessel's length plus 100 divided by 10); so that, should a vessel have greater or less, they would give a percentage of reserve buoyancy in excess or short of that required. In such cases, therefore, the freeboard is modified, being reduced if the sheer is in excess of the standard, and increased if otherwise.

The freeboard required in **sailing-ships** is slightly greater than in steamers, more especially in those of small size. In ships, a good freeboard is valuable in that, as it is accompanied by stability, it reduces the chance of beam-end casualties. And the correspondingly large buoyant power is also valuable, for, owing to the high bulwarks, the deck may hold a large volume of water, which not only tends to submerge the hull, but, by acting the part of a shifting deck-load, may cause a serious list.

A **spar-deck vessel** is not one of full scantlings, the structure being somewhat lighter throughout. According to the actual scantlings, the longitudinal and transverse strength may vary very considerably; here, therefore, the freeboard is governed by the strength of the hull rather than by weatherly qualities. In those of normal strength (as per Lloyd's rules for

1885) the freeboard allowed is that suitable for a vessel of full scantlings, increased for a small vessel by about 50 per cent., and for a large one by about 10 per cent. The difference is smaller in large vessels, because the discrepancy in strength becomes, with increasing dimensions, less pronounced. Many spar-deck vessels are now constructed with heavier topside plating and frames than is specified in Lloyd's rules, in which case their freeboard may be reduced to that of a three-deck full-scantlinged vessel.

Art. 58. Deck erections, such as a poop or forecastle, are most influential in promoting weatherly qualities, particularly if the sheer be small, for they not only assist in lifting the vessel's ends to the advancing waves, but, by acting as breakwaters, prevent them from leaping on board and rolling freely along the deck. A forecastle is of more value in this respect than a poop, for under ordinary circumstances the waves are encountered by the bow, and their tendency to break on board and sweep the deck is here intensified by the forward progress of the ship. In the case of sailing-ships, however, it is not uncommon when running before the wind for high following waves, moving faster than the ship, to break over the stern (a mishap known as "pooping"), to the danger of the ship and crew; such chance is, of course, minimized by the presence of a poop, or quarter-deck. The machinery openings (engine-room skylight, ventilators, and fiddley-gratings) are vulnerable points; being more or less permanently open, should seas inundate the deck, water might pass below with dangerous consequences (Art. 219). Accordingly, practically all sea-going vessels are provided with a bridge-house, which not only protects the machinery casings, but places the fiddley openings at a safe height, well above the upper deck. If there is no bridge, or if it is imperfectly constructed, the freeboard is increased.

Deck erections are disregarded in estimating the reserve buoyancy; for, apart from their slender construction, they may have open doorways, skylights, etc., and before they could contribute a full measure of buoyant effect they would require to be submerged. Their capabilities in assisting to lift the vessel to the waves and in keeping water off the deck depend on their length and height, whether or not they are enclosed by bulkheads at their ends, and on their general strength.

In an **awning-deck vessel**, although the upper 'tween-deck portion of the hull has very considerable buoyant and protective power, it is not, on account of its slender construction, included in the primary estimate of reserve buoyancy, but is regarded merely as an all fore-and-aft deck erection. In such vessels the freeboard is taken from the second deck, this being regarded as the upper one of the hull proper. It is, of course, much smaller than that necessary for a flush-deck, full-scantlinged vessel, having the same dimensions as the hull proper of the awning-decker. The difference varies from about 50 to 25 per cent., according as the vessel is small or large, being less in the latter because, with a deep hull and high freeboard, the height of the awning-deck erection and the importance of its buoyant and protective effects becomes relatively less. If the awning-deck superstructure is built with special strength a still smaller freeboard is permissible.

A **poop, bridge, or forecastle** may be regarded as isolated portions of a complete awning-deck superstructure. As they leave much of the low-lying upper deck exposed to the sea, their effect in promoting weatherly and buoyant qualities is of course inferior, and so the large reduction in freeboard allowed for a continuous awning-deck is modified. It is reduced rather more than in strict proportion to the length of the upper deck

covered by the detached erections. If, for instance, they covered altogether 60 per cent. of the vessel's length, then, not 60, but 50 per cent. of the awning-deck reduction would be made. The freeboard so obtained may be increased if the structural design of the erections is imperfect—if open at their ends, for instance, so that seas, flooding the deck, may freely enter and flood the enclosed space; or if a forecastle is less than 6 feet high, or a quarter-deck less than 4 feet, for in such cases their lifting power and protective effects are inferior (a poop and quarter-deck rank alike if over 4 feet in height). In the actual computation of freeboard—as assigned under the Act—numerous other features of the design, affecting in however small a degree the safety and weatherly qualities of the vessel, are taken into account.

In **well-deck vessels** the erections are extensive. Were it not for the portion of the upper deck exposed in the well, they might be regarded as equivalent to an awning-deck erection (for freeboard purposes a raised quarter-deck, although really forming the upper deck, is reckoned as an erection). In these vessels, therefore, the freeboard to the upper deck may be small, little more than that admissible in an awning decker. As the upper deck in the well may be near the sea level, it is particularly liable in heavy weather to be inundated by the waves; this, however, is counted upon, and special provision made to mitigate any evils which might result, the precise freeboard depending on the extent of such provision. Thus, to permit of the rapid exit of water from the well (which, acting as an additional load, may have a most prejudicial effect on the vessel's weatherly qualities), large freeing ports are cut in the bulwark; the coamings of the hatchway in the well are made extra high, so as to leave less room for water and place the hatch covers at a higher level; and, to permit of the crew passing with safety from bridge to forecastle, an elevated gangway is fitted. Should waves break over the bows, which, owing to the low freeboard, they may often do, the bulkhead forming the front of the bridge becomes a sort of target, and, for the safety of the ship, therefore, it must be strongly built. Sometimes it is constructed with special strength, in which case a reduction in freeboard is allowed. A still further reduction may be made if the bridge-house is so long as one-half the length of the ship, and is so substantially built as to contribute useful strength to the hull.

CHAPTER VII.

Art. 59. A vessel's **keel** is sometimes familiarly described as the backbone of the hull, and, agreeably with this conception, it is commonly regarded as a structural part of special importance. In the early days of iron shipbuilding its construction received an extravagant degree of attention, numerous complicated formations being proposed and tried.[1] Its primary purpose is to stiffen the vessel's bottom, by giving to the detached ribs or frames lying across it fore-and-aft continuity, so that all may share alike in resisting local pressures from grounding or docking. It has another function, important, however, only in wood vessels. In these it always projects beyond the skin planking, so that, being the lowest part, it acts as a fender, or rubbing-piece, should the vessel touch the ground. This is important in a wood ship, because the soft planking, sheathed with felt and thin copper, could not endure even gentle rubbing contact with a hard bottom. The keel itself would suffer and fray away, and to protect it, therefore, a false keel is provided, *i.e.* a plank, bolted in a semi-secure fashion to the bottom of the keel proper. In steel vessels, as the skin plating is not readily damaged by mere contact with the ground, the usefulness of an external keel (Plate 101) disappears in great measure, so much so that it is now usually dispensed with altogether, its place being taken by a thick central strake of shell plating, termed the "flat-plate keel," to which there is united internally an upright plate, termed the "vertical-plate keel" (Plate 102).

An external **bar keel**, or **"hanging keel,"** as it is sometimes descriptively termed, has certain advantages (see Plate 5). From its massiveness and great local stiffness, it is well adapted to distribute the severe local pressures that may result from grounding on a stony bottom. In such a contingency it preserves, to a considerable extent, the thin yielding plating from contact, and perhaps from indentation or perforation. It is also beneficial, to some extent, in checking rolling tendencies, its action in this respect being similar to that of a bilge keel (Art. 355). It is objectionable, however, in that the vessel's draught is increased by its depth, often an important matter, where, in consequence of shallow harbours, bars, or canals, a slight excess of draught may disqualify a vessel for certain trades. And its exposed position renders it liable to damage; in case of violent contact with the ground, it is sometimes bent over to one side.

Flat-plate keels are adopted principally with a view to minimizing the draught. In such a case the lesser fitness of the vessel to take a stony bottom without injury is disregarded, and properly, for grounding, except on a smooth bar or the muddy bottom of a harbour or river, is a casualty

[1] Some of these early keels are illustrated and described in Sir E. J. Reed's work on Shipbuilding.

so little likely to occur that it does not warrant special features in the design, especially if to the detriment of other qualities.

In many large modern vessels a **combination of a bar and flat-plate keel** is adopted (Plate 107). Here a flat and vertical-plate keel are fitted in the usual way, but, riveted outside, there is an ordinary bar keel lying on its side. This is an excellent arrangement; the massive bar gives great local rigidity, and serves as a substantial fender. Unlike an ordinary hanging keel, it is compact and not liable to damage, and increases but little the vessel's draught; further, by giving great stiffness and strength, it permits of a less massive flat-plate keel. Sometimes, in place of a massive bar, a mere strip of plating, $\frac{3}{4}$ inch or 1 inch thick, is substituted (Plate 105). This does not confer much keel-like strength, but serves usefully as a *rubbing-piece*.

Art. 60. Although familiarly described as the backbone of the vessel's bottom, the keel itself only fulfils a minor part of the duties involved. Considering the great size and weight of a loaded ship, it is evident that a bar keel, although massive in itself, would alone be quite inadequate to distribute unyieldingly the intense local pressures to which it may be exposed. To withstand, without bending, the upward pressures due to grounding, or even ordinary sea pressures—acting on the extensive area of the vessel's bottom—a fore-and-aft girder of great strength and stiffness is required. In wood ships the necessary strength is secured by what is practically a duplication of the keel, *i.e.* a **keelson** (a stout log, like the keel proper) is superposed on the cross timber floors, over—but not in contact with—the keel, being united thereto by long bolts passing through the floors. In iron and steel vessels a similar construction was, and is still, adopted, but here the keelson is composed of plates and bars, in the form usually of a powerful I-section girder (Plate 101). Being deeper than a bar keel, and having its material more efficiently disposed, the keelson is really the stronger of the two. As noticed later, other arrangements are commonly adopted wherein the keel and keelson are conjoined as one (Plate 5); but whatever the design, the result sought is a powerful **centre-line girder**. It should be observed that, in regarding a bar keel as a fore-and-aft beam or girder, it cannot properly be considered alone, for rigidly attached thereto are the garboard strakes, which not only increase its thickness or sectional area as a bar, but form wide flanges on either side (see Fig. 6, Plate 85).

Art. 61. Before describing the various arrangements of centre-line girders, it will be well to examine the **efficiency of** the fundamental one just noticed, *i.e.* **a detached keel and keelson**, as adopted in sailing-ships, and in steamers not having a double bottom (Fig. 1, Plate 3). It may be readily shown that, as regards strength and stiffness, the arrangement is not very efficient. The combined strength of two similar beams, so long as they are disconnected, is only double that of one; whether placed side by side, or one on top of the other, they act independently as separate beams. If, however, when superposed, they are united as one, the important element of depth is at once introduced. The strength of a solid rectangular beam varies as the square of its depth, and its stiffness as the cube; by uniting two such beams, therefore, the strength of the combination would be four times that of one of them, and the stiffness, or resistance to deflection, eight times greater. If a further advantage due to the importance of depth were desired, then, instead of fixing the two beams, the one directly upon the other, they might be disposed some distance apart, vertically, and conjoined by a thin distance-piece or web. This arrangement would form a typical girder, for there would be an upper

and a lower flange and a connecting web. In resisting bending stresses, each one has different and specialized duties; while the one flange suffers tension throughout, the other is only affected by compression.[1] The duty of the web is to hold the two flanges at fixed distance, and prevent any relative fore-and-aft slipping movement. To do this it need have no longitudinal strength or continuity; an arrangement of cross, diagonal links, forming the well-known *lattice-girder*, would serve the purpose (Fig. 6, Plate 114).

A **detached keel and keelson** arrangement (Fig. 1, Plate 3) does not, therefore, form, as might at first sight appear, a girder of which the keelson and keel are the top and bottom members respectively, for there is **no proper connecting web.** The floors, although holding them at fixed distance, lack one of the attributes of a web, for, being parallel, they are incapable of checking relative fore-and-aft movement of the two parts. They cannot convey fore-and-aft stresses from the one to the other; with a solid or lattice-link web, a stress on the keel—due to a deflecting force—whether tensile or compressive, is at once communicated to the keelson, and immediately sets up in it a corresponding stress of reverse character. When conjoined only by parallel floors, the two parts cannot co-operate; they act independently, each one contributing only its own comparatively small beam-like strength. That this is so is shown by the diagram Fig. 2, Plate 3. Here the floors have communicated an upheaving force from the keel to the keelson, causing both parts to deflect in precisely the same way; they have evidently acted as separate beams, each with its own neutral axis, for in each one the upper layers have stretched and the lower ones compressed; also, a great amount of relative longitudinal slipping movement has occurred, as is shown by the fact that the end floors and the ends of the keel and keelson are no longer in one straight line. Fig. 3 depicts the same keel and keelson conjoined by intercostal plates; and it will be observed that here the conditions are quite altered, for while the entire keel has suffered compression and has shortened, the keelson has suffered tension and has lengthened bodily by the same amount; the material at the neutral axis, shown by the dotted line, has, of course, neither stretched nor shortened.

Art. 62. It is clear, therefore, that **to secure the full efficiency of the keel and keelson, they must be conjoined by a rigid web.** In practice this is sometimes done by fitting intercostal plates between the floors (Fig. 3, Plate 3, and Figs. 8 and 11, Plate 5). By their means the keelson and the keel—with its attached garboard plates—are at once transformed from independent parts into the top and bottom members of one deep girder, possessing very superior strength and rigidity. The intercostal plates have a further beneficial effect, in that they prevent any approach of the keel and keelson. Under an excessive upheaving or crushing pressure acting upon the keel, the floors would develop a tendency to trip or buckle (Figs. 4 and 6, Plate 3); and, of course, when held erect by intercostal plates, such yielding is most efficiently checked. This is an important matter, for, in cases of damage to the bottom through grounding, failure of the floors by side bending is a common result.

With a **bar keel** the **intercostals** have no direct connection thereto.

[1] As separate beams, the material in each suffers both tension and compression, the lower half being affected by the one and the upper by the other; near the *neutral axis* (at mid-depth) the material suffers little or no stress, and so is comparatively ineffective. When the two beams form separately the upper and lower flanges of a girder, *all* of the material in each is affected by one or the other, tension or compression, and so is thoroughly effective.

There is a very substantial indirect one, however; for the garboard strakes, which are really in one with the keel, are well connected to every floor by double frame angles (the frame angle and heel-piece), and the floors, in turn, are united to and rigidly held by the intercostal plates (Figs. 8 and 11, Plate 5).[1] Intercostal plates are practically always fitted in way of the side keelsons (Fig. 7, Plate 3, and Plate 101); here they have a direct connection to the shell and keelson, but not usually any to the floors. They are, therefore, entirely wanting in fore-and-aft continuity; but this, as already seen, is not essential in the web of a girder. In preventing relative longitudinal straining between the strake of shell plating and the keelson (the upper and lower flanges) they are perfectly capable.

In view of the greater efficiency secured by an intercostal-plate connection between an otherwise detached keel and keelson, Lloyd's rules permit of a slight reduction in the scantlings of the keelson. This will be observed on comparing A and B, Fig. 7, Plate 5. Nevertheless, in vessels having a bar keel and shallow floors, the detached keel and keelson arrangement is nearly always adopted; in sailing-ships it is almost universal. It may be observed that, in practical shipbuilding, to adopt the most theoretically perfect arrangement of parts is not always expedient; the result usually aimed at is an arrangement that combines, in the maximum degree, the qualities of simplicity of construction and of ample strength.

Art. 63. A more perfect arrangement of keel and keelson is that in which the two parts are conjoined, not by intercostal plates, but by a continuous **vertical-plate keel, or "through plate"** (Figs. 12 to 15, Plate 5). This method involves considerable modifications, for the floors, instead of passing across the keel, are now severed and united on either side to the vertical-plate keel; and in place of an ordinary bar keel, one of side-bar type, or a flat-plate keel, is employed. Whatever the type of keel, this through-plate arrangement makes a very perfect centre-line girder; the continuous web not only acts efficiently as a joining medium, but, unlike intercostal plates, confers considerable girder-like strength. But while perfect as regards longitudinal strength, it is not always so when transverse strength is considered, for the floors are all severed at the centre line, and if only connected thereto by short vertical angles and by the foundation plate of the keelson, as shown in Figs. 12 to 14, the strength of the continuous floor is not regained. But although the severance of the floors reduces the strength of the vessel's bottom, this is largely made up for by the much greater strength of the centre-line girder. Thus, in the case of an ordinary detached keel and keelson, the keelson, lying above the floors, can only begin to exercise resistance to upward thrusts when the latter yield sufficiently to throw a stress upon it. Here the floors are directly called upon to transmit the thrust, whereas when the keel and keelson are united as one, the deep and powerful girder so formed exercises at once its full resistance to upward deflecting pressures, quite independently of the floors.

The through-plate construction is not often adopted in vessels having ordinary shallow floors; not only on account of the meagreness and generally unsatisfactory nature of the connection, but because of the increased workmanship involved. In vessels which carry oil in bulk the floors are always of shallow type, butted on either side of a through-plate keel (Plate 26); but here the arrangement is particularly convenient, for the continuous vertical keel forms a suitable lower margin for the central fore-and-aft bulkhead, always fitted in these vessels. The bulkhead

[1] In the early days of iron ship building, bar keels were sometimes formed with a groove in the upper edge, or with a rabbet on the side, to take the intercostal plates.

permits of the suppression of any special keelson, and affords an excellent bracket attachment for the severed floors. The brackets also serve the useful purpose of holding the lower part of the bulkhead erect, so that when exposed to intense upheaving pressures it may stand square to its work. In modern vessels having a double bottom on the McIntyre principle, a continuous through-plate or vertical keel is sometimes adopted, in which case an excellent connection may be secured for the ends of the floors by bracket plates, as shown in Fig. 4, Plate 103.

Art. 64. Notice now the **practical details** of the different centre-line girder arrangements just described. First consider an ordinary **detached keelson** (Fig. 4, Plate 5). In all but very small vessels this is of I-section, being composed of a *vertical plate* with two angles on either edge, the upper pair having a *covering or rider-plate*. In small vessels a bulb plate with double angles, or two bulb angles back to back, is usually substituted, this being a more convenient and simple construction; or a single massive bar of solid section, I or bulb-tee, may be employed. These alternative methods of construction are shown in Fig. 4. A disadvantage in a keelson composed of a single large bar is the complete discontinuity that prevails at each joint; when composed of separate parts the various end joints may be disposed so remote from each other that, even if unconnected, the strength of the whole may not be seriously impaired; nevertheless, when carefully connected, the strength of a single bar may be quite well maintained. The purpose of the covering-plate in a built I-section keelson (Fig. 5, Plate 5) is to reinforce the upper flange of the keelson as a girder, and to stiffen and protect the angles, for, when loading and discharging cargo, the latter are particulary exposed to violent blows. In the early days of iron ship building, when a keelson of superior strength was required, a box formation was sometimes adopted; but although excellent as regards strength, a *box keelson* is awkward to build, and is objectionable in that its interior is not accessible for cleaning and painting. In some cases, also, to secure longitudinal strength, material was massed at the gunwale in the form of a box-girder, of which the deck stringer plate and the upper part of the sheer strake formed the bottom and one side.

In an **I-section keelson** the top and bottom angles are identical. They have a wide and a narrow flange; in the case of the upper pair, the wide flange is disposed horizontally, this being advantageous both as regards girder-like strength and lateral stiffness. The covering-plate is made sufficiently wide to cover both angles, its thickness being that of the vertical plate. The lower angles are usually disposed with the wide flanges vertically. The connection to the floors is made by four rivets at each one, two in the reverse bar and two in the *keelson lug* (*i.e.* a short doubling angle introduced for the purpose). In large vessels the strength and massiveness of the keelson become so great that a mere four-rivet connection at each floor would, under severe stress, be inadequate to hold the keelson rigidly in place, in which case its full capabilities would not be available. Lloyd's rules provide for this by requiring the keelson of large vessels (over 33,000 plating numeral) to have a *foundation plate* (Fig. 5, Plate 5); as this is riveted all fore and aft to the lower angles, it not only increases the strength of the keelson as a girder, but, by the more extensive rivet connection to the reverse frames and lugs, secures a more thorough incorporation with the hull.

Regarding the hull as a large girder, **all longitudinal parts may taper towards the bow and stern,** and, further, regarding the keelson as a backbone to the vessel's bottom, it should evidently be stronger

amidships, where this is wide, than towards the ends, where it is narrow. Accordingly, the scantlings of the keelson are always reduced towards the ends. If its function as a backbone to the vessel's bottom were alone considered, it is evident that in way of the V-shaped sections near the bow and stern, where there is no flat bottom to support, its usefulness disappears. Nevertheless, it is usual to extend it as far forward and aft as practicable, for the sharp fore-foot and heel of a fine vessel are exposed to side-twisting stresses from impacts with the waves, and if composed merely of shell plating, stiffened by cross floors, they might lack rigidity and massiveness. Further, in case the vessel should run aground, bow-on, it is evident that the presence of the keelson over the fore-foot must assist in limiting possible damage.

Notice now the **practical details** of the **intercostal keelson** shown in Figs. 7 to 11, Plate 5. The intercostal plates are considerably thinner than the vertical plate of the keelson, for, as a mere connecting-web, and as regards their duty in holding erect the floors, special strength is not required. For the same reason a single angle connection to the floors is sufficient. The intercostal plates may be connected to the keelson by extending them upwards between its lower angles (Figs. 8 and 11), or by extending the keelson-plate downwards, notching it at each floor (Figs. 9 and 10). The former method, being the simpler, is the one usually adopted. The latter involves extra rivets, awkwardly placed, and the notching of the vertical plate causes points of weakness. In order that the intercostal plates may efficiently transmit to the keelson upward pressures acting on the keel, their lower edges should evidently bear upon it.

Art. 65. A flat-plate keel, having little vertical rigidity, must be stiffened and strengthened by conjunction with an internal vertical-plate keel, which, in vessels having ordinary shallow floors, may be either of through-plate (A, Fig. 12, Plate 5) or intercostal type (Fig. 9). The connection is made by large double angles, of keelson size, continuous or intercostal according as the vertical plate is continuous or intercostal. Large angles are employed because the effect of massiveness is important at this part. In small coasting vessels the intercostal-plate arrangement is usually adopted, for although inferior as a centre-line girder, it is more suitable in other respects. The fact of a small coasting vessel having a flat-plate keel implies that she navigates shallow waters, and is, therefore, liable to take the ground; and as such vessels are usually of disproportionately large beam, and thus require transverse rather than longitudinal strength, the bottom must evidently benefit more by continuity in the floors than by superior efficiency in the centre-line girder. Although, with a bar keel, the intercostal plates may be connected to the floors by a single angle bar of reverse-frame size, with a flat-plate keel, double angles should be employed to minimize the prejudicial effect on the longitudinal strength due to the discontinuity in the lower fore-and-aft angles.

Art. 66. A through-plate keel (Figs. 12 to 15, Plate 5), although serving the same purpose as an intercostal one, has a greater responsibility, for it must compensate by superior longitudinal strength for the loss of transverse strength caused by the severance of the floors; for this reason Lloyd's rules require it to be $\frac{2}{20}$ inch thicker. The connection of the floors on either side of the vertical plate is by *double* angles of reverse-frame size. Two angles give practically double the strength of one, for they share alike in any stress, and the rivets are in double shear. It is evident, however, that this short angle-bar connection would not alone nearly represent the strength of the floor elsewhere, for it would not make good

the continuity of the frame angle and reverse bar, which are the most effective parts of the floor as a transverse girder. The frame angles are well tied across by the shell plating, and a similar connection is provided for the reverse bars by fitting a central fore-and-aft plate on the tops of the floors (Fig. 12), which forms a cross tie for their upper edges, and serves also as an upper flange for the vertical keel plate; and, to connect it more securely to the tops of the floors, short doubling lugs are fitted on either side. Lloyd's rules require this plate to be the same thickness and three-quarters the breadth of the garboard strake. In small vessels it, in itself, serves as a sufficient keelson, but in larger, a bulb-tee or I-section keelson is superposed (Figs. 13 and 14), in which case, to avoid fitting the lower pair of angles, the horizontal plate is fitted in two strips, so as to permit of the vertical plate being extended upwards between them. In some cases, the better to unite the floors on either side, the vertical plate is pierced so that a reverse frame lug may pass through, and thus tie them together. Such ties are well placed to resist transverse stresses due to grounding, for the immediate effect of an upheaving force on the keel is to strain the two half-floors asunder at their upper edges. With a side-bar keel, a similar tie (or frame heel-piece) is sometimes placed in way of the frame angle (or, in a vessel having a double bottom, the frame angle may be continuous from margin plate to margin plate).

Art. 67. As a bar keel is only held in place by its union with the garboard strakes, its incorporation with the internal framework is only that due to the rivets connecting the garboard strakes to the frames (Fig. 5, Plate 5). Just over the keel, therefore, the frame and garboard strake connection is specially important, and so, although elsewhere a single frame angle is sufficient, here a double one is required, and is secured by fitting short angles across the keel, termed "**frame heel-pieces**," about three feet long, and the same size as the frame angles (Fig. 5). If the floors do not actually bear upon the keel, upward grounding pressures acting upon the latter can only be transmitted by the rivets connecting it to the garboard plates; the tendency, therefore, is to shear or loosen them, a result commonly observed after grounding. To relieve the keel rivets, the floors should actually bear upon the keel; the floor plates themselves do not do so, however, for, to facilitate the constructive work, they are kept clear of the heels of the frame angles. The frame angles should take a bearing, yet this they do not always do, and even if they did, their effect in backing up the keel and transmitting pressures would be poor, because, being severed at this point, their ends would be easily distorted. The frame heel-pieces, on the other hand, may be readily fitted so as to bear upon the keel, in which case they form kind of *strong backs*, for they back it up, and convey upward pressures to the floors, to the relief of the keel rivets.

It is only through the medium of the rivets connecting the frame-angles to the floors that pressures from without are transmitted to the hull; and, consequently, after a grounding casualty, it is common to find that where local pressures have occurred these rivets have loosened or shorn. The heel-pieces are useful in this respect, for, by placing the frame rivets in double shear (those over the keel, where grounding pressures are most likely to occur) they greatly increase their strength. Under excessive, upward, crushing pressure the floors are liable to fail by side buckling; the heel-pieces check this tendency, by reason of the more extensive and stable attachment which they afford the floors. They are also useful in making good the loss of strength due to the joint of the frame angles

and the limber holes, especially in old vessels, where the latter may have become enlarged and the floor plates thin by corrosion. Further, by reducing the clear frame space, they increase the stiffness of the garboard plates against such local grounding pressures as might cause indentation; in this respect they are equivalent to an increase in thickness, but, of course, in any case, the garboard strakes are thicker than the others. They are not fitted at the extreme ends of the vessel, but only for three-quarter length admidships, for, owing to the sharp form of the transverse sections at the ends, neither the garboard plates nor floors require the special stiffening effects just noticed; nor are they required when a through-plate keel is adopted, unless it is associated with a detached bar keel. In full vessels, the lower portions of the frame angles at the fore end are doubled for the reasons mentioned in Art. 108.

Art. 68. In a **cellular double bottom** the **centre girder,** or **vertical keel,** is always a continuous plate; and here, of course, there is no transverse weakness, for the great depth of the floors permits of an excellent attachment of their ends, and the inner bottom, or tank-top plating, ties together, very thoroughly, their upper edges (Plate 85). The keel proper, in vessels having a cellular double bottom, may be of flat-plate, side-bar, or ordinary bar type. When of the last description, there is no direct connection with the vertical plate, and a more thorough indirect one must, therefore, be secured by fitting heel-pieces to the frames, and by doubling the angles connecting the ends of the floors to the vertical keel.

Art. 69. Together with the centre keelson, there are four other keelsons, two on either side (Plate 101). One of these, the **bilge keelson,** is placed near the ends of the floors, just below the bilge; and the other, the **side keelson,** between this and the centre (in very small vessels this one is not required). In small vessels both the side and bilge keelsons are formed of two angle-bars, riveted back to back (Fig. 5, Plate 3). When over a certain size (15,000 plating numeral) the side keelson is strengthened by the addition of intercostal plates (Fig. 7); it is a more important keelson than that at the bilge, for, being situated on the flat part of the bottom, its duties are similar to those of the centre keelson, *i.e.* it serves as a backbone, stiffening the flat part of the bottom against upheaving pressures. The intercostals not only strengthen it as a fore-and-aft girder, but much improve the efficiency of the floors and shell plating. They transform the keelson from a mere tie (holding the tops of the floors at fixed distance) into a powerful girder, of which they are the web, the conjoining strip of shell plating the lower flange, and the keelson angles the upper one. They have not usually any connection to the floors, and in order, therefore, that they may be effective in holding them erect, their edges must fit in actual contact therewith. As they are connected to the shell by short angle bars, they so stiffen the conjoined strake as to give it much of the effectiveness of a flat-plate keel. They are discontinued towards the vessel's ends, for the floors, becoming short, do not require vertical support; and the bottom, departing from the flat, does not require special stiffening. In vessels of full form, however, they are carried right forward to the collision bulkhead, for they are required here to stiffen the shell against the special panting stresses described in Art. 108.

Art. 70. In **large vessels of extreme proportions** (having shallow floors), in which the hull begins to require additional longitudinal strength, the **keelsons** are the parts—below the neutral axis—that are called upon to contribute it, the extent of the reinforcement being dependent on the size of the vessel, and on how much the length is disproportionate to the depth. In a small vessel, just over eleven depths in length, the only

reinforcement is the addition of a bulb bar to the bilge keelson; in a large one, having a length so disproportionate as thirteen times the depth, both the side and bilge keelsons are formed as I girders, each with an intercostal connection to the shell, and the depth of the centre keelson is increased by 25 per cent. These reinforcements are only required over the 'midship portion of the hull, for one-half or two-fifths of the length.

Art. 71. In the **design of the keelsons** various arrangements are adopted. Thus, instead of a bulb plate and double angles, it is common to substitute two bulb angles (see D and E, Fig. 4, Plate 5); this is advantageous, in that there is one part less to fit, and shorter rivets. Sometimes, in small vessels, in place of double angles back to back, a large single angle or channel bar is employed, with advantage economically (Fig. 7, Plate 8). As already noticed, the keelsons are connected to the floors by four rivets at each one, keelson lugs being fitted for the purpose. Sometimes, to avoid fitting lugs, the reverse-frame flanges of the bars forming a keelson or stringer are made wide enough each to take two rivets abreast, in the reverse frame only (B, Fig. 2, Plate 5, and Fig. 1, Plate 55). This is not quite so efficient structurally, the line of four rivets across the two bars causing a local weakness.

Art. 72. In resisting upheaving pressures on the bottom, the **transverse bulkheads** are most effective; they not only give direct resistance, but, acting like the piers of a bridge, **support the keelsons at various points,** transforming them from long and flexible parts into comparatively short and rigid girders. This is often seen in cases of damage through grounding, for where the bottom (in vessels having shallow floors) may be set up from the straight, the position of a transverse bulkhead may usually be discerned by the presence of a prominent transverse ridge (Fig. 15, Plate 21). In **sailing-ships** there are **no 'midship bulkheads,** so that, compared with steamers, the bottom is less capable of resisting upheaving forces; and as the keelsons are unsupported from end to end, they form long flexible girders, and so are not very capable of resisting deflecting pressures. For this reason they are made stronger than those in steamers. Plate 4 illustrates Lloyd's requirements; the additions from the normal double-angle formation are only required amidships, and only in large vessels (over 24,000 plating numeral).

Art. 73. In vessels which are so small as not to require an intercostal connection to the side keelson, **wash plates** are fitted (Plate 100). These resemble intercostal plates, but they are not structural parts, for their purpose is merely to check the violent wash of bilge water, with its resulting scarifying action on the cement and floors. They are not required towards the ends, for, owing to the transverse slope of the bottom, bilge water cannot wash from side to side; nor are they required where there is a vertical-plate keel. They may be riveted to the floors, to the shell, or to a fore-and-aft angle bar, fitted like a keelson, for the purpose (Fig. 7, Plate 8). The last plan is the best, for the plates are easily fitted and riveted, and, by keeping their lower edges about one inch above the cement, the desired condition of a large, yet restricted, passage for the bilge water is at once provided. To rivet them to the floors is objectionable, in that these are weakened by the rivet holes. In cases of damage to the bottom, it is common to find the floors of small vessels fractured at such places. Wash plates are subject to rapid corrosion and attrition, so that although thin plates might serve, they would have little endurance; they should therefore be fairly substantial—Lloyd's rules specify a thickness equal to that of the bulkheads. Formerly, as a substitute for wash plates, short pieces of plank were jammed between the floors. In small vessels

whose trade involves frequent grounding in harbour, it is well so to design the wash plates that they may contribute useful strength to the bottom. By connecting them to the shell and to a double-angle keelson, they may be converted, at little additional expense, into a valuable structural part, greatly increasing the strength of the bottom.

Art. 74. Small **coasting vessels which load in tidal harbours** often take the ground at their loading berths. In some cases the ground may be neither smooth nor level, and as the tide may leave the vessel almost high and dry, perhaps when heavily loaded, the bottom, although sufficiently strong for all legitimate afloat stresses, may suffer deformation. It is common, in such vessels, to find the shell plating set up in wavy undulations between the frames, and, in those having shallow floors, that the whole bottom has moved up in places. Small vessels not having a double bottom, and which, owing to the machinery being at the stern, have only one long hold, are the most liable to suffer injury; for the keel and keelsons, being deprived for so long a distance of the support of transverse bulkheads, deflect readily, and give but poor assistance to the shallow floors. In such vessels, therefore, which by the necessities of their trade may require to load or discharge on the ground, the **strength of the bottom should be increased** beyond what is usually necessary. The additional strength is most advantageously applied in the form of stronger floors and reverse bars, and in thicker shell plating, and the addition of an intercostal side keelson, where, as in these small vessels, there may be none, at once greatly increases the strength and stiffness of the bottom.

Art. 75. Notice, now, some **practical details** in connection with **bar keels.** They are composed of separate lengths, scarph jointed, the different parts varying in length from 30 to 60 feet, usually some multiple of the length of the garboard plates (Art. 499). They may be of **steel or iron, forged or rolled.** Formerly, only forged iron was used; now, rolled bars are largely employed, for they are cheaper and no less efficient, When rolled, they are usually of steel, for bars of this material, unlike those of iron, may be obtained of practically any length, this being limited merely by the question of convenience in transport, and manipulation in the shipyard. From the point of view of efficiency, regarding the keel as a massive stiffening and protecting ridge, there is little to choose between steel and iron; steel, however, being the stronger, is the better material. Comparing forged with rolled bars, there is again little difference; forged material is generally harder and stiffer, but, not being homogeneous, it is less trustworthy, and is much more costly. A rolled steel bar has much greater ductility than a forged iron one; it may be bent and twisted without fracture, and although such ductility may not be advantageous in a keel, the perfect uniformity of the material, the long lengths procurable, and the correspondingly small number of joints, as also its greater cheapness, are sufficiently pronounced advantages.

The different **lengths of keel** are **scarph jointed** (Fig. 11, Plate 5). Lloyd's rules require the length of the scarphs to be nine times the thickness; those of the British Corporation specify three times the depth of the keel. The scarphs are machined so as to fit with perfect contact throughout. The holes in the various lengths are drilled before the keel is laid, but to ensure that those in the scarphs may be precisely opposite each other, they are left blank in one of the parts, and are drilled through after they are fitted together. To minimize this drilling, which is usually done by hand, the holes left blank are those in the thin half of each scarph. It is important that the holes should be fair, for, owing to the large size of the rivets, the hammer blows have little staving effect on their shanks, so that

cavities, remaining unfilled, might result in unsound rivets—a not uncommon condition in keel rivets. When the keel is laid, the different joints must be rigidly united. This is done by small supplementary *tack rivets*. The ordinary rivet holes cannot be used, for they are required for the garboard plates, and to bolt them would interfere with the fitting of the latter. The tack rivets are usually placed near the upper edge of the keel, so that their closing effect, being concentrated here, may permit of the top of the scarph being caulked before the garboard plates are fitted.

The smallest **size of keel bar** given in Lloyd's rules is 6 by $1\frac{1}{8}$ inches, and the largest 12 by $3\frac{3}{4}$ inches. In fulfilling its purpose as a massive fender or stiffening ridge, the precise dimensions of the keel, so long as the sectional area is maintained, are unimportant. Sometimes it is reduced in size, and the garboard strakes, which may be regarded as outlying flanges, proportionately increased in thickness. The garboard plates are always double riveted to the keel; if very large, treble riveting is sometimes adopted. The **rivets** may be arranged in **chain or zigzag** fashion. With zigzag riveting, the cross sectional area of the keel is not reduced by two holes abreast; but care should be observed that the butts of the garboard plates do not foul the rivets. In small keels a zigzag disposition is advantageous, in that it enables the two rows of rivets to be placed closer together. Keel rivets are never less than $\frac{7}{8}$ inch diameter. With chain riveting this would necessitate an overlap in the garboard plate and keel of $5\frac{1}{4}$ inches; but in a 6-inch keel there is only about $4\frac{1}{2}$ inches available, on account of the knuckle of the garboard plate, and because, to prevent injury to the lower caulked edge of the latter, it must be kept clear of the bottom of the keel (Fig. 6, Plate 85). It is for this reason that small keels are so much deeper in proportion to their thickness than large ones.

In **coasting vessels** which often touch the ground, particularly those which frequently creep up rivers at low tide, the **bottom of the keel** gradually **wears away**, so much so that in those of considerable age the shanks of the lower rivets become exposed. This occurs principally at the after end, owing to the prevailing trim by the stern. It is remedied by fitting **shoe plates**, *i.e.* U-shaped plates embracing the keel. In such vessels this wasting action should be provided against by making the keel deeper, so that it may project well below the edge of the garboard plates. With a flat-plate keel, it is well to fit a rubbing strip at the after end, as shown in Plate 105. In small vessels, such as steam trawlers and yachts, the keel and stem are often formed of a stout bulb bar (A, Fig. 4, Plate 5). The bulb protects the edges of the garboard strakes, and provides substance for the above wearing action. The scantlings of such a keel are usually the normal, increased by the bulb.

Art. 76. Side-bar keels are principally adopted in vessels having a cellular double bottom, and in which a hanging keel is desired (Figs. 3 and 7, Plate 85); otherwise it may be adopted with ordinary floors and a through-plate keel arrangement (Figs. 12 to 15, Plate 5). Structurally, a side-bar keel is particularly efficient, for, being absolutely rigid, it is capable of transmitting intense local pressures without any straining of contiguous parts. It is objectionable in that, being composed of five different thicknesses, it is not easy to secure fair rivet holes and sound rivets. As special care is required to fit and drill the various parts, it is somewhat costly in workmanship, and, in case of damage to the bottom through grounding, repairs are difficult and costly. The size of the side bars is such that, when combined with the vertical-plate keel, the external keel so formed may be the size of an ordinary bar. The different lengths of side bar are merely butt jointed (Fig. 7, Plate 85); this is admissible,

because, with five different thicknesses, a complete discontinuity in one does not materially reduce the strength of the whole. The joints, of course, should be disposed as far apart as practicable. The side bars, or "slabs," as they are sometimes termed, are usually of rolled material, steel or iron. Rolled iron bars cannot be obtained in long lengths, and it may be necessary, therefore, to avoid too great a contiguity in the joints, to weld two or three together, as a preliminary process. The edges of a rolled bar are slightly rounded, and so, to secure a good caulk, the lower edge of the vertical plate should be kept about $\frac{1}{4}$ inch up from the bottom of the keel; this also protects the caulking from wear and tear due to contact with the ground (see Fig. 3). To bind the side bars to the vertical keel until the garboard plates clamp all together, small tack rivets are introduced at intervals of about 2 feet. The different methods of fitting the side bars and drilling the holes are described in Art. 500.

Art. 77. A **flat-plate keel** is merely a centrally disposed strake of shell plating (Plate 102). To fit it for its more important duties, it is made thicker than the ordinary shell by about 50 per cent., which, with the stiffening and supporting effect of the internal vertical plate, gives it all the rigidity necessary to withstand local pressure. It is usually disposed as an outside strake, but not invariably. The outside position is advantageous in that, however flat the vessel's bottom, it occupies a lower level than the contiguous garboard strakes; the latter are then less likely to take contact with the ground—an important matter—as they are less capable of an unyielding resistance. Further, in case of damage to the keel plates through grounding, they are, when placed outside, more readily removed for repair; but inasmuch as the lighter garboard plates are even more readily damaged by such a casualty, this circumstance loses its importance. The outside position facilitates the constructive work, for the two lower landing edges may be caulked without the consecutive removal of all the keel blocks; it avoids the necessity of tapering the garboard frame liners; when the keel plate is doubled, the doubling, being inside, does not require such careful fitting and caulking, and it permits, if required, of the keel being fitted at a late period, after the garboard plates are in place.

The **scantlings of flat-plate keels** given in Lloyd's rules vary from 30 by $\frac{8}{20}$ inches in a small vessel to 36 by $1\frac{3}{4}$ inches in the largest. When so great a thickness as 1 inch is exceeded, it was formerly the practice to double the keel plate (for half-length amidships), making it altogether about $1\frac{1}{2}$ inches thick; this avoids the difficulty of manipulating such massive material, and also secures greater uniformity in strength. If only connected by a single strap, a joint may be regarded as an unavoidably weak spot; when, therefore, the required thickness of keel is obtained by two plates instead of one, then, as only one-half of the material is jointed at one spot, the inherent weakness at each joint is reduced by half. Now, however, a doubling is usually dispensed with, and compensation made by increasing the breadth and thickness of the keel and garboard strakes and the thickness of the vertical keel. When the thickness of the keel plate does not much exceed 1 inch, its joints are usually lapped like others of the shell, and treble or quadruple riveted (Figs. 7 and 8, Plate 18, and Fig. 6, Plate 102); otherwise they are butted and strapped (Figs. 9 to 12, Plate 18). In large vessels (over 26,000 plating numeral), overlapped butts are quadruple riveted, and butted ones provided with treble-riveted double straps (Fig. 12). When the keel is an outside strake, single straps, if required, are fitted within, as shown in Figs. 9 or 10. Towards the vessel's ends the keel plate tapers in thickness by about 25 per cent., the full thickness being maintained for three-fifths of the length. Such a reduction

in massiveness is permissible owing to the diminution in the longitudinal stresses towards the ends, and because, as the loaded hull is lighter here than at the full 'midship part, the keel is less likely to suffer intense pressures.

In large high-class vessels it is now common to fit a massive bar, or "**slab keel,**" on the outside of the flat-plate keel (Plate 107). The rivets connecting this also unite the fore-and-aft angles to the flat-plate keel. The various lengths are scarph jointed, horizontally. The ends of the bar, at the bow and stern, may be merely tapered down on to the plate keel, or the stem and stern-frame may be arranged to receive them without apparent break (Fig. 2, Plate 87). In the absence of a massive bar, it is now not uncommon to fit a **rubbing strip,** about 1 inch thick (Plate 105).

CHAPTER VIII.

Art. 78. Formerly **the frames** were always made by riveting together two angle-bars, the frame angle and reverse bar or reverse frame; such are known as *built frames* (B, Fig. 5, Plate 6, and Plate 101). Now they are as often composed of a single bar, of Z channel, or bulb-angle section; such are known as *solid frames* (C, D, and E, Figs. 5 and 6, Plate 6). The built frame is still largely employed, for it has several advantages; in the following it will be considered first.

The term "frame," when used in a general sense, signifies each combination of three parts—the frame angle, reverse bar, and floor plate. The built frame is convenient because of the independence of the reverse bar; this may be discontinued on the vessel's topside, where a reduction in strength is admissible (Plate 100), and it may leave the frame angle in way of the floor plate, where it would be of no use, and follow the upper edge of the floor, where it is required for stiffness and strength and as a means of attachment for the ceiling planking. Also, individuality in the frame and reverse bar is advantageous in the "deep frames" of large vessels, where a single bar might be too massive to manipulate; when solid frames are adopted, for instance, the built formation is often retained for those at the bow and stern, in which the curvature and bevel may be considerable. The reverse bar may be regarded as a reinforcement for the frame angle. In very small vessels the strength of the latter may be ample without it; in such it is merely fitted across the floor plate, but as strength is required at the bilge, and as to stop it short where the floor also terminates would cause too sudden a reduction in strength, it is extended to the upper part of the bilge. In Plate 100 the reverse bars are extended to the upper part of the bilge and to the gunwale alternately.

Art. 79. An angle bar, alone, is a very inefficient frame. Whether viewed as a rib of the hull, or as a stiffening bar for the thin shell plating, **a frame is essentially a beam.** To be efficient, therefore, its cross sectional area should be symmetrical about its neutral axis or centre of gravity. A single angle is not at all symmetrical about its neutral axis; if bent as in Fig. 11, Plate 6, the material at the toe, remote therefrom, suffers a much greater stress per square inch than the larger mass forming the flange; having a small sectional area, it readily draws out, or, under compressive stress, crinkles, or buckles sideways (the relative straining of the material at the toe and heel is shown by the short dark lines T and H, Fig. 11.) By providing an inner flange (or bulb), symmetry is at once established; the material on both edges, being equidistant from the neutral axis, suffers the same stress, and, by giving an equal share of resistance, the strength is greatly increased. The importance of massing material at the inner toe of the frame angle becomes even more marked when the frame is considered—as it should be—in conjunction with the shell plating which it stiffens. As noticed in Art. 22, each frame may be regarded as

composed of itself plus a strip of shell plating a frame space in breadth (Fig. 11, Plate 6). With a single frame angle, the combination is evidently very inefficient as a beam, for its neutral axis is practically coincident with the wide outer flange; the material here—by far the greater part of the whole—can suffer little stress, even when that at the inner toe of the frame angle is strained to the breaking point.

It is clear, therefore, that in a stiffening bar, such as a frame, the bulk of the material should, for the greatest efficiency, be concentrated at the inner edge. Nevertheless, in practice, a single bar is sometimes the most suitable formation; in the case of a small vessel, for instance, whose frames are single angle bars, say 3 by $2\frac{1}{2}$ by $\frac{5}{20}$ inches, the addition of an inner flange, or reverse bar, would increase the strength, but as this is already sufficient, there would be little or no advantage in so doing, and there would be the disadvantage of increased weight. It is true that, while maintaining the same strength, the addition of an inner flange might, by increasing the efficiency of the frame, permit of so considerable a reduction in its size or thickness as would result in a reduction of the total weight; but in a cargo vessel a frame of the above small size is, as regards the resistance of wear and tear, if anything, too slender already (the width of the flanges must, of course, be maintained for efficient riveting). But even in a large vessel, having massive parts, the comparatively inefficient single angle bar is largely employed, the frames in the upper 'tween decks, for instance, and alternate frames in cellular double bottoms, also bulkhead stiffeners and deck beams, are frequently formed of single angle-bars. Here it is suitable chiefly for reasons of economy. In practice, structural refinements, although conducing to greater theoretical efficiency, are not always advantageous. They would be if, while without seriously reducing the general massiveness, they so lessened the weight of structure as sensibly to increase the vessel's carrying or earning power. In most cases, however, such refinements, although perhaps increasing the efficiency of the particular parts, would not, by increased lightness, so appreciably improve that of the vessel for general trading as to warrant the increased cost of construction involved by the modification. In ordinary shipbuilding it is usually found more desirable to simplify and reduce the number and variety of parts, rather than to combine a larger number of lighter ones for the sake of greater theoretical efficiency. In practice, therefore, the necessary strength is often secured by the simple method of giving massiveness to the structural parts, which, though clumsy from a theoretical standpoint, is economical, and has the advantage of giving greater endurance of wear and tear. In merchant vessels the foregoing considerations greatly govern the structural design, in warships to a much smaller extent (Art. 183).

Art. 80. As already noticed, the **frames may be regarded from two stand-points**, as forming the skeleton of the hull, maintaining its transverse form; or as mere stiffening bars to the slender shell, holding it against the tendency to collapse under sea or other pressures. To fit them for their duty in the first of these aspects, the only requirement is that, together, they shall be sufficiently strong. With the same weight of material this might be complied with by making each one very strong and their number proportionately small, or by employing lighter ones in larger number, *i.e.* more closely spaced. Their duty as mere stiffeners to the shell requires that they shall be closely spaced; in resisting bulging tendencies the plating between them acts like a beam, and as, in such, the flexibility varies as the cube of the length, a small reduction in the frame-spacing must evidently have a marked influence on the rigidity of the shell. Stiffness in

the shell is an important matter, for any appreciable lateral straining would be fatal to the integrity and watertightness of the structure, the various rivet connections would soon loosen and the joints leak. In the first iron vessels the frames were placed close together, 16 or 18 inches, instead of the present 24 inches, and the shell plating was thick. This followed as a natural consequence of the habits of thought acquired in building wood ships, for in these the timber frames, supporting the thick planking, were almost conjoined (on the bottom they often were conjoined), and it appeared that, to support properly thin iron plating, numerous closely spaced frames were necessary.

The **frame-spacing** adopted in modern vessels of ordinary construction varies from 20 inches in a small one to 27 inches in a large one; but a 24 or 25-inch spacing is that prevailing in the majority of vessels. When so great as 26 inches, Lloyd's rules require the rivets connecting the frames to the shell to be spaced 6 dias. apart instead of the usual 7 dias. This is evidently proper, for a wide frame-spacing means a smaller number of frames, and, therefore, a smaller number of rivets binding the shell to the framework; if, for instance, the frames were made extra massive and spaced 4 feet apart instead of 2 feet, then, with only half the number of frames, the duty of the frame rivets, whatever it might be, would be doubled. In some vessels the normal frame-spacing is exceeded, usually in large vessels, where a 30-inch, and even a 36-inch spacing, is adopted. In such, to maintain the general transverse strength, prejudiced by the smaller number of transverse parts—the frames, beams, and pillars—a suitable increase is made in their scantlings, the shell being thickened to maintain its rigidity under the wider intervals of support. The same frame-spacing is usually maintained all fore and aft; sometimes, however, it is reduced at the bow, especially if elsewhere it exceeds 24 inches, for the plating is then better able to resist impact with floating ice, and the bow is strengthened generally against panting stresses and collision (Arts. 107 and 116). The frame-space is measured in a fore-and-aft line, and it follows, therefore, that, at the bow, owing to the horizontal slant of the sides, the distance between the frames, measured on the shell, may be much greater, which constitutes another reason for a reduced spacing at this part (see distance HK and HL, Fig. 7, Plate 6). In vessels of full form the frame angles on the bottom are doubled abaft the collision bulkhead, for the reason mentioned in Art. 108. In warships the frame-spacing is usually much greater than in merchant steamers; it varies considerably even in the same vessel; amidships, in way of the cellular double bottom, where there are numerous longitudinals, it is usually 4 feet, but towards the ends, where the frames are mere bars, it may be 3 feet or less, while, to secure rigidity under the engine, numerous additional frames may be introduced (Plate 113). In such vessels the transverse form is maintained not by the frames alone, but to a very large extent by the numerous bulkheads and plated decks.

Art. 81. Amidships the two flanges of the frame angles are at right angles, but towards the bow and stern, owing to the inward slant of the side, they meet at an obtuse angle (see Fig. 7, Plate 6). These **frames** are said to be "**bevelled.**" To dispose the frames everywhere at right angles to the shell would increase their efficiency as stiffeners, for, in resisting local collapse of the side, the transverse flange, when not square to its work, at once develops a tendency to shirk its duty by folding over still further from the square, as shown at A and C, Fig. 7. But although greater efficiency would be secured by a right-angled disposition, there are practical objections. In making the frames, each one would have to be

twisted throughout its length in order that it might conform to the varying inward curve of the side; and to distort in this way the frame bar, while maintaining its fair and proper curvative, would not be easy. Again, there would be difficulty in connecting it to the straight-across transverse parts, the beams and floors (F, Fig. 7). In any case, excepting the frames near the bow and stern, the departure from the square is so slight as not appreciably to affect their general efficiency. In some vessels having very bluff bows, a few of the terminal frames are worked on the square principle; here, where the bevel would be excessive, there is real advantage in so doing. In wood ships the timbers at the bow and stern are usually worked square to the side, such being termed "cant timbers."

The frames are so bevelled that the angle between their flanges is obtuse, *i.e.* the bevel is an "**open**" one. It follows, therefore, that all frames forward of the flat 'midship portion of the vessel must face aft, and those abaft it, forward; in the flat 'midship portion they may face either way. A "shut" or "**close**" **bevel** is objectionable in several respects; the bevelling work is difficult, for, even when done with care, the heel of the bar is seldom in precisely the same plane as the flange (A, Fig. 8, Plate 6), so that, when riveted to the shell the contact is imperfect. Also, as the one flange masks the other, it may be difficult to punch the rivet holes and insert and hammer up the rivets. The bevel of the reverse bar is, of course, identical with that of the frame angle.

Art. 82. The **frame angles are fitted in one length** from keel or tank margin plate to gunwale, and this even in the largest vessel. It is easier to make them so, for steel bars are procurable of any length, and when in one piece the whole may be heated and bent in one operation. In damage repair work, to avoid renewing the entire frame angle, joints are often introduced, connected by bosom pieces (Art. 280). These are not detrimental to the strength, for, as a rib or stiffening bar, a frame is only subject to deflecting stresses, and the presence of a joint piece, by doubling the sectional area of a considerable portion of the frame, really increases its stiffness. Their clumsy, patchwork appearance and the additional weight involved by the joint piece is, of course, objectionable; but this is more a matter of sentiment, important, nevertheless, when the sale of the vessel is in question.

Art. 83. In ordinary framing, the **reverse bar** is of smaller scantlings than the frame angle; the thickness is usually about the same, but the latter has a wide and a narrow flange, whereas in the reverse bar both flanges are narrow. The scantlings of the frames required by Lloyd's rules, for vessels of varying size, are given in Plate 4. In ordinary framing the reverse bar is usually so fitted that its fore-and-aft flange is flush with the inner toe of the frame (B, Fig. 5, Plate 6); to secure the advantage of depth, it would be better to make it project, retaining just sufficient overlap for a proper connection, as in the deep built frame shown at B, Fig. 6; but the constructive work is facilitated somewhat by the flush disposition, and it avoids the inaccessible crevices mentioned in Art. 93. In many cases one flange of the reverse bar is half an inch wider than the other, when so, it should be placed fore and aft, for then the desirable condition just noticed of a concentration of material at the inner edge is secured. In practice this advantage is usually neglected. Lloyd's rules require the full scantlings of the frame angles to be maintained for three-fifths of the vessel's length amidships; towards the ends a reduction in thickness is allowed of $\frac{1}{20}$ inch. In the case of the reverse bars, as massiveness is important, and as they are specially subject to deterioration, no reduction is made.

The **reverse bars**, like the frames, are usually fitted **in one length** on either side. In the case of small vessels having ordinary floors, they are sometimes worked in one length for both sides; this may be readily done, for they are short and light, and as they are usually without knuckle at the centre line, they may be easily bent to shape with one heat. In other cases they may be worked **in three pieces**—a straight central one, extending across the floor from bilge keelson to bilge keelson, and two others from these points upwards. The straight piece is fitted on the opposite side of the floor plate, so that the ends of the other two may scarph with it, and thus dispense with joint pieces and with two keelson-lugs. The absence of a joint over the keel is advantageous as regards strength, for it is here that the greatest tensional stress occurs when the vessel sits on her keel, an important matter in small coasting vessels, which are liable to take the ground (Art. 20). When jointing a reverse bar (which, as in the case of frame angles, is practically only done in damage repairs), it is a common practice to fit merely a flat strap on the fore-and-aft flanges, taking only two rivets in either bar (Fig. 9, Plate 47). This does not make good the strength, and as continuous strength in the reverse bar is relatively quite as important as it is in the frame angle, they should, evidently, be jointed with no less efficiency (Art. 280).

Art. 84. In very small vessels the **reverse bars** all **terminate** at the upper part of the bilge; in rather larger, alternate ones are continued upwards to the gunwale (Plate 100); in still larger, they extend, alternately, the one to the gunwale, and the other to the second deck or to the hold stringer representing it. Under a quarter-deck, where the vessel's side is suddenly increased in depth, they extend upwards to an extent governed by the greater depth. In large sailing-ships they all extend to the upper deck (Plate 101), and in large steamers of extreme proportions, all, for half length amidships. In steamers of awning-deck type they all terminate at the second deck. In a poop, bridge, and forecastle only the frame angles are carried up. In the case of a forecastle, however, if the vessel is of large size (over 18,000 plating numeral), alternate reverse bars are extended to the forecastle deck. When plunging into head seas, the bows are exposed to severe concussive blows; this becomes more pronounced in large vessels, for they lift less smartly to the waves, and, having greater speed and weatherly qualities, are able to pursue their course, pounding through the waves with irresistible force. Hence the necessity in large vessels for strong framing on the forecastle side.

On the quarters, the sides lie at an angle often approaching the horizontal, so that, when plunging stern-under, they are peculiarly liable to blows of a collapsing nature. The frames, moreover, are here comparatively weak and flexible, for, lying at an angle, their span from deck to deck is long. To provide, therefore, the necessary strength, Lloyd's rules require that at this part—abaft the after peak bulkhead—**all the reverse frames**, in place of alternate ones, shall **extend to the upper deck**, but only in vessels over 20,000 plating numeral. The additional stiffness so secured is also useful in reducing the tendency to vibration, which, owing to the proximity of the propeller, is here specially pronounced. In some vessels, where the quarter is particularly wide and flat, the unsupported side may be more than 12 feet wide between the decks. When this is so, the ordinary frames, even when reinforced as above, would have an excessive duty, and in such cases, therefore, a double-angle stringer should be fitted midway between the decks; in large vessels it is worked intercostally, and is bracketed to the transom plate.

To strengthen the vessel's bottom **under the machinery**, all the

floors of this region are provided with **double reverse bars.** In small vessels not having a double bottom, the supplementary ones may stop short at the bilge keelson; but in larger they are carried round the bilge to the bilge stringer. In large vessels, and in those of high power, the side framing of the machinery space is specially reinforced by web frames (Art. 96).

Art. 85. "**Rise of floor**" is the term used in referring to the sharpness of a vessel's bottom. In most vessels the frames leave the keel at a slight upward angle, continuing in a straight line towards the bilge, and then curving upwards; the rise of floor is the height which the 'midship frame would attain if extended in a straight line to the half-breadth line (the distance AB, Plate 100). Many modern cargo vessels are designed with practically no rise of floor, the bottom being almost flat—in some cases quite flat—amidships (Plate 106); in the majority, however, there is a rise of from 6 to 12 inches; in some of the older types of fine-lined sailing-ships the rise of floor is as much as 8 feet, but these vessels are, of course, very inferior as cargo carriers. With a small rise, the upper edge of the 'midship floor plate may (when of shallow type) run across the keel as a straight, level line, tapering and curving upwards towards the bilge so as to join the frame, without abruptness, at an elevation of twice its depth over the keel. To preclude excessive taper, Lloyd's rules require the depth of the floor, at three-quarters the vessel's half beam from the centre line, to be not less than half its depth over the keel. In a vessel having a considerable rise of floor, this rule may require the upper edge of the plate to leave the centre line with an upward inclination (Plate 101). Formerly it was usually so inclined in all vessels, in order to secure the advantage of a reduced tonnage; for at that time the measurements used in computing the tonnage were taken in a stereotyped manner, and as the lowest breadth ordinates were measured on the top of the floor, a slight rise made them zero. In fine-lined vessels, such as yachts, in which the lower part of the 'midship section is triangular, the foregoing rule as to the maintenance of the depth of the floors near the head is inapplicable; here, therefore, they are simply made a little deeper and are carried straight across, meeting the frame below the bilge (Fig. 14, Plate 6). In such vessels there is no well-defined bilge requiring the stiffening effect of floor plates, and they are not subject to the severe transverse stresses of cargo vessels. It is only those floors that lie within one-quarter of the vessel's length amidships that run up the bilge to double their height at the keel. Beyond this, as the bilge disappears, they rise less and less, until, near the bow and stern, they are carried straight across (Plate 78). By levelling the floors in this way towards the bow and stern, a capacious hold and a maximum of flat floor area is secured for the stowage of cargo.

Art. 86. In small vessels the **floors**, being short and light, may be fitted **in one piece** from bilge to bilge. In others the 'midship floors are fitted **in two pieces**, for if in one they would be too long and cumbrous to manipulate on the bending slabs (Plates 100 and 101). The joints may be placed at the centre, over the keel, or at the side, about three feet out, alternate ones to port and starboard. As regards efficiency in resisting upheaving stresses, the latter disposition is the better, for, regarding the joints as weak spots, they are then better distributed, the line of weakness being zigzag in place of straight fore and aft. The joints are lapped and treble riveted; if butted, Lloyd's rules require double straps. The full **thickness of the floors** is maintained for three-fifths of the vessel's length amidships, beyond this it is reduced by $\frac{1}{20}$ or $\frac{2}{20}$ inch. Under the engine, where massive and rigid framing is essential, all floors are increased

in thickness by $\frac{1}{20}$ inch; and under the boilers, where corrosion may be rapid, by $\frac{2}{20}$ inch.

Art. 87. At the bow and stern, over the **fore-foot and heel**, the vessel's sections form a sharp V, so that the **floor plates** lose their girder-like character. Here they are increased in depth, and serve the useful purpose of uniting the two sides, which, being flat, require a maximum of support against panting stresses (Fig. 12, Plate 6). At the extreme **after end of screw vessels** the frames meet at a more acute angle than at the bow, and in fine vessels they are swollen, or bossed, around the shaft tube (Fig. 9, Plate 6). The sides of the hull have here an important duty in holding the stern frame; the forward post forms a bearing for the shaft, and as it directly supports the overhanging propeller—a live load with excessive vibrating tendencies—it should be specially rigid (Fig. 8, Plate 29). With the sides of the ship close together and almost parallel, the hull, narrow and fin-like, is not naturally well-fitted to confer the necessary transverse rigidity to the post; it is strengthened, however, as far as practicable, by greatly increasing the depth of the floors, so that the sides, instead of being two separate flexible surfaces, are bound together as one rigid whole. Further, the shell plating contiguous to the post and in the vicinity of the tube is increased in thickness, and in some cases the frame angles in this region are doubled. As a result of inferior rigidity at this part, the large rivets connecting the shell to the post often loosen or break, and similarly with the riveting of the adjacent frames and shell joints. Such weakness is commonly observed as a consequence of the breaking of a propeller blade, for, with the loss of symmetry, the centrifugal force and vibrating effect of the propeller may be excessive. In ordinary vessels the floors in way of the tube are fitted in two pieces, one above and one below the tube. In large fine-lined vessels (particularly twin screw), where the tube may be long, one or more floors may be arranged to support it; they are thickened or locally doubled, and may be accurately bored to take contact with the surface of the tube, or clearance may be left and contact secured by driving in wedges. In twin-screw vessels hoops of angle bar are sometimes fitted to secure a connection to the tube, or the latter may be provided with collars.

Art. 88. Lloyd's rules require the **floor plates** (when of ordinary shallow type) to extend right down to the **heel of the frame angle**, leaving, of course, the small clearance necessary for the fitting of the shell. For the mere purpose of a rivet connection, the overlap of the floor plate and frame angle need not exceed 3 inches, and so, with frames $4\frac{1}{2}$ or 5 inches deep, the edge of the plate might be kept well up from the heel of the bar. A good overlap is advantageous, however, for, as it is the lower margin of the floor that bears the brunt of grounding pressures, the double thickness gives massiveness to withstand it—often, while elsewhere uninjured, this marginal part of the plate suffers distortion. Grounding pressures can only be conveyed to the floor plate by the rivets uniting it to the frame angle; and consequently, after grounding it is not uncommon to find these rivets loosened or shorn, due to the frame angle having been forced upward over the face of the floor plate. A wide overlap gives a more rigid union, due to the more extensive faying surfaces; the rivets, of course, are reeled or slightly zigzagged, so as to draw the two surfaces into intimate contact (Plate 101).

Art. 89. Where the **outer ends or "heads" of the floors** or tank margin brackets pass **between the frame and reverse bar**, a tapered liner is fitted (see Plate 101). In light-scantlinged vessels the thin floor plate itself is sometimes thinned down by hammer and anvil, and in other

cases the reverse bar is joggled (when hot, during the bending process, or by the hydraulic riveter). Amidships, the floors (of shallow type) curve gradually into the frame, so that the reverse bar, in leaving the one to follow the other, is not sharply bent; forward and aft, however, the meeting of the two bars becomes more abrupt, so that the reverse bar may require to be sharply kneed. Near the stem and stern the upper edges of the deep floors meet the frames so squarely that the reverse bars cannot easily be bent to follow them; here, therefore, a short, independent bar is usually fitted across the floor, or the edge of the floor may be flanged (Fig. 12, Plate 6). The stiffening bar or flange stops short on either side, but as the reverse bar is continued down for a short distance, it makes good the discontinuity. A similar plan is followed with solid frames, at their junction with the floors or tank margin brackets (Fig. 2, Plate 106, and Fig. 1, Plate 102).

Art. 90. In each floor plate **limber holes** or **water courses** are provided, over the keel and beyond the intercostal side keelsons (Plate 101, etc.). Their purpose is to permit of bilge water flowing fore and aft to the pumps. They vary in size from 2 inches in a very small vessel to 3 or 4 inches in a large one; in some cases they are made semicircular (Fig. 1, Plate 106). In small vessels having shallow floors, care should be observed that the holes are not too large; in some cases those towards the bilge, where the floor is shallow, are so large as to sacrifice perhaps 30 per cent. of the strength; in case of damage to the bottom through grounding, the floors are very liable to fracture at these places. The holes are, of course, punched above the frame angle, so that, unless the cement is very thick, bilge water would remain locked in each floor space. To permit, therefore, of complete drainage, small supplementary **drain holes** are punched through both the floor and frame angle, close to the heel of the latter; as they are small (about 2 by 1 inch), they do not appreciably weaken the frame angle (Plate 101). In the case of the deep floors at the bow and stern, limber holes must be punched at the precise level to which it is intended to fill with concrete, so that nowhere may water find a permanent lodgment (Fig. 9, Plate 6).

Art. 91. The ends, or **heels, of the frame angles** butt against each other over the bar keel, and are connected by heel pieces (Fig. 5, Plate 5). Formerly the ends were flattened so as to bear fairly upon the keel (A, Fig. 6), for which purpose, when the rise of floor was considerable, they were heated in a smith's fire; now this is usually avoided by cutting the ends of the frame angles as shown at B, Fig. 6. In a vessel having a vertical-plate keel in connection with a side-bar or flat-plate keel, they are usually cut quite clear of the side bars or fore-and-aft angles, thus providing natural limber holes, well placed at a low level (Plate 102). With a side-bar keel the frame angles are sometimes fitted in one piece from margin to margin, being run through holes cut in the vertical-plate keel. Near the bow and stern, over the heel and fore-foot, the frames in very fine vessels may meet at an angle so acute as to necessitate their being overlapped and riveted to each other (C, Fig. 6, Plate 5). Formerly a knife-like form at the fore-foot and heel was thought necessary to minimize resistance, and, accordingly, the sides of the hull were often so close together at these places as to make it a difficult matter to rivet the shell. In modern vessels this is avoided by swelling the frames outwards in way of the heel and fore-foot, giving these parts a **club-footed formation** (Fig. 13, Plate 6); and this formation is adopted even in fine-lined vessels, for although apparently less suited for easy motion through the water, it is found not to be so in reality. Where the aftermost frames are **bossed around the**

shaft tube, there may be so little clearance between them and the tube that their projecting flanges may require to be cut away to clear it; in such case, if several frames are cut, they should be doubled, making them of **T** section; or the boss plates should be thickened. In large, high-powered vessels it is common, for the sake of rigidity, to double systematically these terminal frames. Modern cargo vessels are usually so full that only the aftermost frame need be bossed, and in such case it is common not to boss it, but to cut it away entirely in way of the tube.

Art. 92. As already noticed, to secure for the side stringers and keelsons a four-rivet connection at each frame, short reverse-bar doublings or **keelson lugs** are fitted (Fig. 1, Plate 5). In small vessels in which the frames have no reverse bars, and with frames of bulb-angle section, the fitting of two lugs is usually avoided by employing one having a flange wide enough to take two rivets in each fore-and-aft angle of the stringer, in which case they are made extra long, so as to take four rivets through the frames (Fig. 3, Plate 5). In ordinary lugs there are only two rivets connecting them to the keelson or stringer angles, and so it might appear that, for equality of strength, two would also suffice for connecting them to the reverse bar; in practice, however, the latter connection is always made with three rivets, for as it is through these rivets that pressures from without are communicated to the keelson or stringer, they are subjected to a direct shearing stress, whereas the two in the other flange—taking the keelson angles—are affected by no stress at all. In vessels having shallow floors, the centre keelson lug also serves as a joint piece for the reverse bars; it should, therefore, be sufficiently long to take several rivets in either end of the latter; this is particularly necessary when the floor plates are jointed over the keel, so as to reduce the accumulated weakness of so many joints. The two end rivets should, of course, fall near the ends of the lug, for any excess of length beyond these represents useless material; often great carelessness is displayed in this matter. As the fitting of the lugs is light and simple work, it is generally entrusted to lads, and, as a result, it is often badly done; the fore-and-aft flange may not lie fair with the reverse bar, and the bevelling may be inaccurate; such discrepancies are often made good in a clumsy manner, by inserting washers or liners (see Figs. 7 to 10, Plate 80).

Art. 93. Deep frames are simply ordinary ones increased in depth by about 50 per cent. They may be of built or solid type (Fig. 6, Plate 6). When built, the frame angle and reverse bar are usually identical (Plate 105), the work of making the frames being facilitated when the two bars are alike. The overlap of the bars (as required by Lloyd's rules) is 3 inches; in an ordinary single riveted joint, with $\frac{3}{4}$-inch rivets, it would be $2\frac{1}{2}$ inches; but in the case of the frames there is the rounded toe, and a margin of width is desirable to allow for discrepancies in the position of the holes, these being punched in a rough and ready fashion. Formerly the reverse bar was disposed as shown in Fig. 15, Plate 6, but now it is usually placed as shown at B, Fig. 6, or in Plate 103, this disposition permitting of a better connection of the beam knees and stringer lugs. If fitted as in Figs. 15 and 16, Plate 6, there occurs a vacant space or crevice between the projecting flange of the reverse bars, the beam knees, and the stringer lugs. It is impossible to scale and paint these crevices properly, and, as a result, serious corrosion may occur. In way of the beam knees liners are sometimes introduced, but, unless the projection is large, there is insufficient width to rivet them properly. In very large vessels the frames may be so deep that the projection of the reverse bar beyond the frame angle may be sufficient to take the lugs or beam knees (Fig. 16). In such cases, however, the

rivets connecting the frame and reverse bar in way of the knees should be more closely spaced, the better to resist the thrusting and pulling effect of the beams.

Deep frames are not often employed in vessels having **shallow floors**; when they are, the reverse bar may be jointed below the bilge with a bar of normal scantlings, fitted across the floor (Fig. 2, Plate 6). In large vessels deep frames may be very massive, in some they are 12 inches deep; when so large it is not always practicable to employ solid bars, for they may be too heavy and stiff to bend round the bilge and manipulate in the usual way; when over 10 inches deep the built formation is usually adopted, except in the case of channel or Z frames, for these may be split at the bilge (to form frame and reverse frame) where the sharp curvature occurs (see Figs. 1, 3, and 4). Bulb-angle frames are not often split, for the bulb portion does not form an efficient substitute for a reverse frame.

Art. 94. Of **frames of solid section** there are three varieties in general use—the **Z, channel**, and **bulb-angle** (C, D, and E, Fig. 6, Plate 6). As regards efficiency, they are superior to a built frame (B, Fig. 6), for in the latter the double thickness due to the overlap, being situated near the neutral axis, represents ill-disposed material; with the same sectional area, therefore, a Z or channel bar is the stronger.[1] The extra material due to the double thickness at the overlap, although inefficient, does, of course, contribute strength, and in order, therefore, to secure equality in strength, a solid frame must either be thicker or deeper than a built one. As tabulated in Lloyd's rules, frames of Z or channel bar are from $\frac{1}{20}$ to $\frac{2}{20}$ inch thicker, and, when large, $\frac{1}{2}$ inch deeper.

As a stiffening bar, a bulb-angle frame is less efficient than a Z or a channel, for as the sectional area of the bulb is not equal to that of a flange, the neutral axis is not at mid-depth; the difference, however, is somewhat reduced by the circumstances that a flange is wounded by holes. To secure, therefore, in a bulb-angle frame, the strength of a built one, it is made both thicker and deeper than would be necessary for a Z or a channel ($\frac{1}{20}$ inch thicker and 1 inch deeper than a built frame).

As a substitute for built **frames, Z bars** have long been employed, but of late years they have been largely superseded by bulb-angle and channel bars, these being more convenient in several respects. They were first adopted, no doubt, because of their resemblance to the familiar built frame. Comparing a Z with a channel bar, the latter is the superior theoretically, for, having greater symmetry of section, it is less liable, under severe stress, to shirk its work by canting sideways (C, Fig. 7, Plate 6); this becomes more marked in those frames which are bevelled, for they have, as it were, an initial cant. To bend a Z frame to shape is awkward, for, not lying flat on the slabs, it must be propped up; and its heel does not touch the scrive line (Figs. 5 and 6, Plate 83). A channel bar may be easily manipulated, for it lies flat on the bending slabs, its heel touches the scrive, and both flanges may be bevelled by hand simultaneously. The circumstance that the inner flange of a channel frame has a close bevel is not really objectionable; it would be if it were the shell flange,

[1] In considering the strength of a *built* versus a *solid* frame, account must be taken of the circumstance that the two angle bars—connected by a row of rivets—are not united with perfect rigidity. The sectional area of the connecting rivets is not equal to that of the solid bar in the same longitudinal line, and so, under the longitudinal shearing stress set up by a deflecting force, the built frame yields more readily than a solid one of similar section; it is neither so stiff nor so strong. An interesting study of this subject will be found in a paper by Mr. Stanbury and the late Mr. Read, *Trans. Institution of Naval Architects*, 1894.

for the contact of the faying surfaces might be imperfect. The fact that the inner flange of a channel frame masks the other does not seriously interfere with the shell riveting; were the bar very shallow it might, but such frames are usually employed in vessels of considerable size, where they are at least 6 inches deep, so that a dolly, or holding-up hammer, of special type may be readily used (Figs. 18 and 21, Plate 47). The rivet holes in a Z frame may be punched in any machine; in the case of a channel bar, a modification is required on account of the lower flange (Plate 115). With Z frames, the beam knees and floor plates must be fitted on the side of the web next the shell flange, and so, by cramping the width of the shell flange, may, in the case of small frames, interfere with the riveting (Fig. 3, Plate 6). With channel frames, the notches in the stringer plate are smaller, and permit of a better intercostal shell connection (Fig. 5, Plate 102, and Fig. 1, Plate 19).

Although **bulb-angle bars** have long been employed for beams, keelsons, and bulkhead stiffeners, it is only comparatively recently that they have been used for frames. For this they are eminently suited, however, and the apparent blindness to their advantages affords a curious illustration of the conservative influence of habit. The absence of an inner flange was regarded as a disqualifying feature, for it appeared to be incompatible with a proper fixture of the wood sparring, also there appeared to be a difficulty in securing the usual four-rivet connection for the side stringers. Neither of these matters are of any importance, for the sparring may be fixed by cleats, in the portable fashion now commonly adopted with all types of framing (Fig. 1, Plate 56); and, by fitting an extra large lug, the necessary stringer connection is readily secured. Although not long in general use for ordinary framing, bulb-angle bars have long been employed to a limited extent in cellular double bottoms, for the alternate frames on which there are no floor plates. They are now very largely employed for the side frames of both large and small vessels. The formation has several important advantages: it is economical in workmanship, for there is no inner flange to bevel; the bars are easily manipulated, for they lie flat on the bending slabs; they may be cut and punched like an ordinary angle bar, and, when riveting the shell, the bulb, unlike a flange, is never in the way. A bulb, moreover, is an excellent substitute for a flange, for, being massive, it is better able to resist wear and tear. A flange suffers seriously from corrosion, for as its back surface is not readily accessible, it is seldom properly scaled and painted (Art. 463). A bulb offers a small surface to corrosion, so that the percentage of material or strength lost is small; and, as it may be kept well painted and free from scale, there may be little or no corrosion. As already seen, when regarded, theoretically, as a stiffening bar, a bulb angle is somewhat less efficient than a Z or a channel; to secure equality in strength, therefore, it must be somewhat heavier.

The **form and proportions** specified in Lloyd's rules for **bulb-angle and other bars** are shown in Figs. 1 to 5, Plate 74. In their manufacture the flanges might be made thicker than the web, but Lloyd's scantlings assume an equal thickness throughout. The web may be made of almost any required depth; 12 or 15 inches is about the largest bar ordinarily used is shipbuilding (for deck beams). On the other hand, there are difficulties of manufacture which preclude in the flanges a greater breadth than $3\frac{1}{2}$ to 4 inches. If required, the two flanges of a Z or a channel bar might be of different breadth; in warships they sometimes are, but not in merchant vessels.

Art. 95. With built frames, alternate reverse bars may be discontinued in the upper 'tween decks; with solid ones a similar reduction can only be

made by **shearing off the inner flange** (Plate 107). As a rule, therefore, the bars are left intact, which simplifies the work, secures the desirable quality of uniformity in strength, permits of the height between decks being increased beyond the usual minimum of 8 feet, and, in spar or awning-deck vessels, of a reduction in freeboard. **Solid frames** are not often employed in vessels not having a double bottom, for, with shallow floor plates, built framing is particularly suitable. Even in vessels which have a double bottom the frames near the bow and stern are often of built type (though solid elsewhere), for they are here associated with ordinary floors, and, as they may be sharply curved and bevelled, they may be manipulated with greater ease when in two separate bars. When solid frames are associated with ordinary floors they are usually discontinued in way of the latter, and jointed with an ordinary frame angle, a reverse bar being fitted on the upper edge of the floor (Figs. 1 and 2, Plate 6). If a Z, channel, or bulb-angle frame were carried right down to the keel, the inner flange or bulb would represent ill-disposed and comparatively ineffective material. This, and the making and fitting of a separate frame angle, might be avoided, of course, by shearing off the inner flange or bulb; but to do this would be laborious and wasteful. Bulb-angle frames, however, are sometimes carried right down to the keel. A case of this kind is illustrated in Fig. 11, Plate 26; and here the tops of the floors are carried straight across and flanged, and brackets fitted at the bilge. With Z or channel frames over 6 inches deep it is common to **split the bar** in way of the floor plate (or tank margin bracket), so that the two angle bars, thus formed, may serve, the one for the frame and the other for the reverse bar (Figs. 3 and 4, Plate 6). When the floors are long, however, the split portions are jointed with separately fitted angle bars (Fig. 1), for to split a long bar and then bend the two parts to different curvatures, while being awkward and costly, would secure no special advantage.

In vessels having a **double bottom**, the side frames are united with those within the tank by the **margin bracket plates** (Figs. 3 and 4, Plate 6, and Plate 17); these may be regarded as the outer extremities of the floors, severed by the margin plate; they are, therefore, subject to the same requirements as to height, *i.e.* they must extend up the bilge to at least twice the depth of an ordinary floor plate at the keel (Art. 85). With built frames, the frame angle and reverse bar are conjoined with the bracket plate just as they are with ordinary floors (Fig. 14, Plate 17). With solid frames, if not split, a short supplementary reverse bar is fitted on the upper edge of the bracket (Fig. 16), or the latter may be flanged (Fig. 18). The frame bar may be extended unmodified right down to the tank margin, but if the bracket is long, weight may be advantageously saved by removing the inner flange or bulb, here of little service (Fig. 18, Plate 17, and Plates 102 and 107). If this be done, the full section of the bar must be maintained for some distance below the upper edge of the bracket, so as to cover the weak spot caused by the discontinuity in the supplementary reverse bar, or its substitute, the flanged edge of the bracket plate. When the ceiling planking on the tank top is laid on bearers, the tops of the brackets are sometimes raised so as to dispense with the bearers at this part (Fig. 3, Plate 6).

Art. 96. Although **web frames** may not be required in the cargo holds, they always are **in the machinery space**—except in very small vessels. Regarding the hull as a large girder, it is amidships, in way of the machinery space, that longitudinal bending stresses and those of a racking or twisting nature are most intense, a circumstance often aggravated by the irregular distribution of weight and buoyancy prevailing in this

region. Evidently, therefore, it is amidships that the greatest efficiency in the structural design should prevail, but, unfortunately, it is just here that it is often most difficult to secure, for, to make room for the engine and boilers and meet various requirements, modifications very prejudicial to the continuous rigidity and strength of the hull have often to be made. The lower deck or tier of beams is always largely, if not entirely, suppressed, numerous beams in the decks above must be severed to form the necessary openings over the engine and boilers, and, in large vessels, the plated decks may be largely cut away (see Fig. 5, Plate 8, Plate 27, and Fig. 1, Plate 28). To restore the transverse strength and give general rigidity to the hull at this important part, the side framing is increased in massiveness by the introduction of web frames, which are extended not merely from the bilge to the lowest deck, as in the cargo holds, but right up to the gunwale.

In the **machinery space** of small, **low-powered vessels**, in which the ordinary structure is little disturbed, the side framing need be no more massive than in the holds. In those over a certain size, however (16,000 plating numeral), Lloyd's rules require three web frames to be fitted. With a machinery space of the average length, this would place them 8 or 10 feet apart; whereas if fitted in the cargo holds, merely to make good the absence of a lower tier of beams, they would be from 12 to 16 feet apart. In larger vessels, web frames are required at intervals of 8 feet, or less.[1] In vessels constructed on the deep-frame principle, which, of course, is equivalent to a regular series of web frames, a sufficient special reinforcement may be obtained by only one or two deep web frames. It should be observed that as the machinery space is usually short compared with a cargo hold, the end bulkheads are most effective in giving transverse rigidity to the structure; they compensate in great measure for the absence of numerous beams.

The foregoing requirements refer more particularly to cargo vessels having engines of moderate power. In large, **high-speed ocean liners**, having a **machinery space** extending over perhaps half the length, still greater reinforcements are necessary. In some of these every alternate frame in way of the engines, and every third in way of the boilers, is formed as a web frame. Here they are introduced not only to strengthen the hull, but to reduce vibration—a very important matter in a vessel carrying numerous passengers, on whose comfort her commercial success in great part depends. When the boilers are placed close to the vessel's sides, there may be insufficient space to fit web frames, and in such cases the ordinary frames, when of channel section, are usually doubled. This may also be necessary in the engine room of twin-screw steamers; for with two engines abreast, and extensive auxiliary machinery, there may be insufficient space athwartships for web frames. In such case the side stringers, otherwise of deep formation, may require to be shallow and massive, and perhaps increased in number. It should be remarked that framing material arranged in this way—shallow and massive—is much less efficient than when in the form of deep, girder-like, web frames.

In **vessels of high power** the tendency of the engine to cause **vibration** of the hull is very marked; to reduce it, flexibility in the structure must be avoided. Not only must the bottom framework under the engine be exceptionally massive, but the sides of the hull in this vicinity should have rigidity in excess of that prevailing elsewhere. Just as vibrations in a flexible wand become more decided towards its extremities, so does the tendency of the hull to vibrate become more pronounced in

[1] The *Bureau Veritas* give a general rule, namely, that in the machinery space the web frames shall be one-third closer together than if it were a cargo hold.

parts remote from the engine seat. The comparatively slender upper structure overlying the machinery space, being deprived of the tying effect of through beams and pillars, is thus particularly susceptible to vibration, and in view of this it is usual, in large high-powered vessels, not only to provide numerous web frames, but greatly to increase their efficiency in way of the 'tween decks, by making them about twice as wide as below (Fig. 5, Plate 8). When so wide, they form diaphragms, or partial bulkheads, rather than girder-like web frames. In affording rigidity against vibration and other straining tendencies, they are, therefore, particularly efficient, for, while perfectly supporting the side, they hold the decks at fixed angle therewith, and, by vertically uniting the various decks, confer in high degree the quality of continuous rigidity, so effective in checking vibration. To examine the hull of a large ocean liner conveys the impression of solidity and strength quite incompatible with transverse straining, yet when tossed about in stormy seas—like any small vessel—the apparently rigid structure gives constant evidence of stress and strain; the upperworks amidships, deck erections, bulkheads, cabin partitions, etc., may creak and strain quite perceptibly as the vessel labours and rolls from side to side. In such vessels, not only is great longitudinal strength required, but, in quite equal degree, great transverse stiffness, particularly in the topsides amidships, and this is best secured by fitting wide partial bulkheads of the above description. It is evident that a mere increase in the scantlings of the side frames, even though they were doubled in number, would produce little of this special binding effect.

Art. 97. In way of **large hatchways**, where the vessel's sides are deprived of the support of numerous through-beams, conditions similar to those just noticed prevail. If the hatchway is of moderate size—say, less than 26 feet long—the transverse strength may be sufficiently maintained merely by increasing the scantlings of the end beams; if longer, it may be necessary to introduce web frames, or to increase the strength of the existing frames by increasing their depth or fitting additional reverse bars. The additions actually required depend, of course, on how much of the structural strength, longitudinal and transverse, is sacrificed. In the case of a hatchway, say, 26 feet long, one web frame at mid-length might suffice; if larger, another might be fitted at each end. A web frame at mid-length is well placed to resist the local racking or panting of the side that might result from the absence of through-beams; and when at either end, they are well placed for distributing the intensified thrust or holding effect of the end beams. In conjunction with the latter, the rigid hoop-like effect, so effective in preserving the transverse form, is well secured. Evidence of the greater tendency of a vessel's side to pant or rack in way of long hatchways is sometimes observed in the straining of the rivets connecting the side-frame brackets to the tank margin plate; those in consecutive frames, on both sides of the ship, becoming loose and leaky, while those clear of the hatchway may be unaffected. On this account these angles should be doubled in way of large hatchways.

In **small one-deck vessels the hatchways** are often so long and wide that the deck plating on either side is reduced to a narrow strip. When this is so, its duty in affording longitudinal strength and lateral rigidity is greatly increased, and so, to fit it for its larger responsibilities, it should not only be made thicker, but should be well held, in fixed horizontal position with regard to the side, for, of course, any yielding or tendency to yield would at once reduce its efficiency. In ordinary cases the necessary support is given by pillars. But as pillars are in the way, and are liable to displacement, the better plan is now commonly adopted

of substituting for the pillars large sweeping bracket plates, as shown in Fig. 7, Plate 8. These have evidently a better holding effect, and if fitted in conjunction with web frames, the whole is equivalent to the marginal part of a bulkhead, which, by giving great transverse rigidity, increases the efficiency of both the deck and side.

Art. 98. Web frames are also introduced **at various places** as local reinforcements. In large high-speed vessels they are sometimes fitted near the bow below the lowest deck, as a provision against the excessive panting stresses which accompany fine lines and high speed forcibly maintained in heavy weather. In some cases they are fitted at the after end to strengthen the side, where, owing to its transverse slope, the distance from the lowest deck to the floors may be excessive. In twin-screw vessels they are fitted to strengthen the bossed or overhanging part of the side (Fig. 5, Plate 30). They are also fitted at places where sudden discontinuities of structure and irregular distribution of weight might induce concentration of stress and local straining. At the ends of deep tanks, for instance, if the end bulkheads are not extended above the tank top, a marginal portion is, in the form of a partial bulkhead or web frame (Fig. 5, Plate 24, and Fig. 4, Plate 25); and in the case of shelter or awning-deck vessels, where the bulkheads may stop at the second deck, web frames must be fitted above this to the upper deck. When large cargo or coaling ports are cut in the topsides amidships, severing one or two frames, it is usual to fit short web frames from deck to deck, so as to maintain the rigidity of side, prejudiced by the severance of the frames (Fig. 2, Plate 60). In large sailing-ships web frames are fitted in the poop or bridge-house, under the rigging, so that the lightly constructed sides of these erections may be relieved of any exceptional stress from the pull of the rigging.

Art. 99. Web frames vary in **structural design**; some different arrangements are shown in Fig. 10, Plate 6, and Plates 7 and 8. When of normal construction (A and C, Fig. 10, Plate 6), the web plate is of the same thickness as, and connects to, an ordinary frame angle, its inner edge being stiffened by a single large face angle, or by two of reverse-frame size. In many cases the web-frame shell angles are made of $3\frac{1}{2} \times 3\frac{1}{2}$ inch bars, like those on the floors of a double bottom (B, Fig. 10); the large frame angle, however, is advantageous in the case of a vessel having two decks, and in which the web frames stop at the second, for, by merely extending it upwards, it serves as the 'tween-deck frame, it being admissible to dispense with alternate reverse bars at this part. When a web frame stops at a lower deck, the frame above, if of Z, channel, or bulb-angle section, may be scarphed with it (Fig. 1, Plate 8), or be connected to the deck over the web by a bracket, or be carried down unmodified in way of the web frame (Fig. 3). In small vessels which carry coal, ore, etc., a face bar of ordinary light scantlings has little endurance; being exposed to bumps and blows, it becomes quickly battered and broken. In such, therefore, the face angles should be extra thick, or a massive bulb bar or two half-round mouldings may be substituted (D and E, Fig. 10, Plate 6).

When **web frames** are fitted in conjunction **with shallow floors, their** breadth should be well maintained at their juncture therewith, the contour of these particular floors being modified to suit (Fig. 2, Plate 7). Very commonly it is convenient to taper them, so that, without interfering with the bilge keelson, the face angles may pass under it, the one terminating here, and the other continuing as the ordinary reverse bar; this is also advantageous in that it reduces the disturbance of the ceiling planking, and interferes less with the bottom of the hold as a platform for cargo.

When **web frames** are fitted in conjunction **with a double bottom,** the tank margin brackets to which they connect should be enlarged, so as to curve into and joint with them above the bilge; the face angle may then sweep down without abruptness to the tank margin (Fig. 4, Plate 6). Very commonly, however, to simplify the constructive work, the web plate is worked simply as a parallel strip, its lower end being lap-jointed to an ordinary margin bracket (Fig. 7, Plate 7). In such a case, the face angle, instead of being kneed to the top edge of the bracket, is sometimes merely continued down a foot or so below the edge of the bracket, which, if not flanged, is provided with a short independent angle bar, carried across the web, as shown in Fig. 2, Plate 8.

In those cellular double bottoms which have floors only on alternate frames, it is evident that it is in way of the floors that the web frames should be placed, for then the floor plate within and the web without form a continuous hoop from keel to deck. If placed in way of a frame not having a floor plate, the margin bracket within the tank should be made extra large (Fig. 1, Plate 102). As noticed in Art. 34, the brackets which form the lower part of a web frame should have a substantial connection to the margin plate, either by double angles or a gusset plate. Web frames amidships which are straight are fitted in one piece; when curved, they may be heated and bent, or they may be cut to shape from the solid. When of great length, or when the curvature is considerable, one or more joints are introduced, which are overlapped and treble riveted (Fig. 2, Plate 7, and Plate 106). Those web frames which are only introduced locally (at hatchways, or in the machinery space) are not usually associated with the deep side stringers adopted with web framing. When the stringers are of the ordinary double-bar or intercostal formation, it is common not to disturb their continuity at the webs, but to pierce the latter and pass them through; and care should be taken to make good the strength of the web where reduced by the aperture, by fitting a face strap, or by doubling the face angles (Fig. 8, Plate 7). Unless the web frame is very broad, however, it is better to sever the side stringer, and secure the necessary continuity by face plate, brackets and lugs, as shown in Fig. 6, Plate 7.

When a **web frame** extends through the 'tween decks, the **'tween-deck portion** is fitted as a separate part (Figs. 2, 4, 7, Plate 7); and, similarly, in way of a wide hold stringer the web frame is severed and bracketed (Fig. 3). The bracket of the 'tween-deck portion is very commonly fitted as a fore-and-aft gusset (Fig. 4), for, being then more compact, it interferes less with the stowage of cargo. Otherwise, to dispense with the fitting of bracket plates, the web plate may be made extra wide, as shown in Fig. 7.

It is desirable that the rigid stiffening effect of a **web frame** should extend horizontally across the deck at which it terminates. This is done by increasing the strength of the particular **beam to which it connects,** and fitting an extra large knee plate, double riveted (Plates 7 and 8). The strong beams of I section required in the machinery space (and under the quarter-decks of large vessels) should fall on web frames, for then the connection may be a very substantial one, in keeping with the massive character of the beam itself (Fig. 4, Plate 8). Together with a horizontal gusset plate to the stringer, at which level the beam is placed, there should be a vertical bracket plate both above and below, for in this way the holding power of the beam and the stiffening capabilities of the web frame and stringer are most thoroughly developed.

If, in the machinery space, **coal bunker bulkheads** fall in suitable position, they should be made to serve as **web frames.** The ordinary

bunker plating is thin, however, and although the bulkhead may be wide, this does not make up for its slenderness; under pressure from without it would readily buckle. To give it, therefore, the stiffening effect of a stout web frame, its marginal plate should be thickened and a vertical stiffener placed near the shell.

Art. 100. In **twin-screw vessels,** if the shaft pierced the sloping side it would form a long oval hole, severing many frames. The bluffer the vessel, the shorter would this oval hole become; if so bluff that the side stood square with the keel, the shaft would enter it squarely and make a circular hole, so that the end of the shaft tube within might be squarely flanged thereto. In practice, precisely this effect is secured by forming a local swelling on the ship's side (Figs. 6 and 7, Plate 30), having a square-across termination through which the shaft may enter, and to which the end of the tube may be fixed. There are different methods of forming the swelling, or **bossing.** In small bluff vessels of the barge type, it may be so short, fore and aft, that, instead of modifying the hull, a casting may be fitted as shown in Fig. 8. In such cases the hull may be built as if without provision for the shafts, whereupon, these being lined off, the necessary oval hole may be cut, severing as required one or two frames and the wood pattern for the casting fitted outside.

In **larger twin-screw vessels** the foregoing method is inapplicable, for the casting would be too large and the hull too much weakened by the severance of numerous frames. Here, therefore, the side of the ship is bossed. The swelling begins at the first frame which would approach inconveniently near the shaft; this one is only slightly bossed, but those abaft it more and more (Figs. 6 and 7, Plate 30). **The bossing** may terminate at that frame whose local swelling is so great that the shaft, passing it, may be quite clear of the ordinary side beyond; a thick transverse plate is then fitted across this frame, completing the integrity of the shell plating by uniting that surrounding the bossed frames with that on the normal surface abaft them. This plate supports the after end of the tube, which, forming a bearing for the shaft, must be very rigidly held. If the plate stood alone it would, of course, be incapable of giving proper support to the tube; but a high degree of rigidity is at once secured by placing within the hull at this part a transverse bulkhead, complete or partial, of which it may form a projecting portion (Fig. 7). Sometimes, as a substitute for the last bossed frame and tube plate, a casting is employed, having flanges to take the shell plating, and large transverse palms to take the bulkhead. Such castings are always adopted in wood-sheathed vessels; in these it is made of bronze, so as to fulfil the necessary condition that at no place under water may any of the steel structure be exposed (Art. 470).

When arranged as above, a long portion of the shaft lies exposed beyond the bossing, and, to support its outer end at the propeller, a two-leg **propeller strut** is fitted, as described in Art. 262 and illustrated in Plate 35. In many cases the outboard portion of the shaft is uncovered, but in high-class vessels it is encased in a detachable tube, which, by covering irregularities, serves to reduce water disturbance (Fig. 7, Plate 30). In practically all large vessels a similar effect is now secured by extending the bossing right aft to the propeller (Figs. 1 to 5), and by fitting, instead of a clumsy two-leg strut, a single-leg **horizontal bracket,** as illustrated in Plates 36, 37, 38. In this way there are no salient parts to create water resistance. The after end of the shaft tube is supported by the bracket, and its forward end by one of the bossed frames, suitably strengthened by a thick plate, forming part of a transverse bulkhead; and to support the shaft bearings which fall within the bossing, deep floor

plates, web frames, or partial bulkheads are introduced. When the frames are stiff and massive, perhaps of 6 or 8-inch channel bars, it would be a difficult matter to bend them to the sharp triple curvature required at some parts of the bossing. In such cases, therefore, they are not bent outwards in the usual way; they are, where the swelling is small, but further aft, where it is considerable, they are carried straight down, or are made to clear the shaft by an easy inward curve, the place they would otherwise occupy, on the outer swelling, being taken by short independent angle frames (Fig. 3, Plate 30). The latter form a supplementary outer framing for the bossed portion of the side, the structural strength being maintained by the continuous main frames within. When the frames are of built type, the frame angles may be bent outwards to form the bossing, the reverse bars being carried down with their ordinary curvature, or set in as required to clear the shaft. In some cases the frames contiguous to the propeller bracket, where the bossing becomes very thin and fin-like, are carried straight down, the shell plating occupying its usual position, and the plating of the boss being fitted as an external addition; this arrangement gives greater security against water entering the hull in the event of fracture of the shaft and tube.

CHAPTER IX.

Art. 101. The number and massiveness of the **side or hold stringers** depends on the depth of the vessel's hold. Lloyd's rules in this respect are exhibited graphically in Plate 4. There are three distinct classes of side stringer—the ordinary, which run continuously fore and aft without any special points of support; those which are fitted in short lengths between web frames; and the wide stringer plates fitted in conjunction with widely spaced hold beams. Although, for convenience, Lloyd's rules specify certain formations, others are frequently adopted, which, while giving equal strength, satisfy other requirements of the builders or owners. Some different formations are shown in Figs. 1 and 2, Plate 5; Fig. 1, Plate 7; Figs. 1 to 5, Plate 9; Fig. 1, Plate 55, and Plate 103. It will be observed that the number of component parts varies; in some it is reduced to a minimum, by flanging, or by employing channel or Z bars, or bars of special massiveness. When a plate is flanged, Lloyd's rules require it to be of greater thickness for the reasons noticed in Art. 184. In comparing the advantages of differently formed stringers there are several matters to consider. As regards structural efficiency, those are superior which are most symmetrical. That shown at A, Plate 103, for instance, is more efficient, theoretically, than that shown at B, or in Fig. 2; for, with a face bar above and below, its lateral rigidity is greater, *i.e.* under horizontal bending forces there would be no initial tendency to cant or fold over on the ship's side. Nevertheless, it is generally preferred to place only one large face bar below, for, owing to the fewer parts, the stringer is cheaper to construct; the flush upper surface is advantageous as regards cargo stowage, for the salient edge of an upper angle is obstructive and is readily battered and damaged, and the trough-like formation forms a lodgment for water, grain, etc. In vessels which carry grain in bulk, holes are sometimes punched in such stringers, so that the grain may fall through and fill the empty spaces that might occur below; and in some cases the stringers are sloped downwards from the vessel's side, so that no grain may lodge thereon (Fig. 2, Plate 103). The latter arrangement is evidently not an efficient one structurally, for, having a permanent cant, a tendency to increase it must occur with every lateral bending force; to check the tendency, supporting bracket plates must be fitted at close intervals. The intercostal plates of the side stringers are fitted in long lengths, scored or notched to pass out between the frames (Fig. 13, Plate 89). They not only act as a connecting web between the shell and the stringer bars, but the continuous portion between the latter adds useful sectional area to the whole; to secure fully the latter advantage, however, the joints of the plate must be properly connected, a matter not always attended to.

Art. 102. In the case of the **wide stringer plate fitted in conjunction with hold beams** (Figs. 1 to 5, Plate 9), bracket plates are

fitted at alternate frames to hold the plate square to its work and support it against the weight of superimposed cargo. Even with stringers other than hold-beam stringers, if wide and massive, similar brackets may be required to secure a sufficient incorporation with the side of the hull (Fig. 1, Plate 103). The breadth of a hold-beam stringer plate is usually the same as what would be required for a lower deck; but in most cases, while maintaining the same, or a greater sectional area, the breadth is reduced, so that, by projecting less far into the hold, the stringer may not interfere so much with cargo stowage. In way of the machinery space, and more particularly abreast of wing boilers, it may be greatly reduced in breadth, or it may be formed like the side stringers below, all, however, being increased in massiveness, or perhaps another one may be added. The **size of the face angles** (Plates 9 and 102) depends on the distance between the beams, *i.e.* on the length or span of the stringer. When short, a single angle bar of keelson size may suffice (Fig. 2, Plate 9); if long, double angles with a face plate are required, or an extra large single bar, of channel or bulb-angle section (Fig. 3). A single bar is, of course, advantageous in simplifying the constructive work and in maintaining a flush upper surface; when it is very deep and massive, however, a more rigid fixture than that due to the row of rivets connecting it to the stringer plate becomes necessary, and is secured by a lug connection to the ends of the supporting brackets (Fig. 4). The continuity of the face bars is broken at each hold beam, but any prejudicial effects are amply provided against by the local increase in the sectional area of the stringer due to the gusset plates, under or over which the face bars should extend (Fig. 8). In some cases the face bar is kneed to follow the edge of the gusset (Fig. 9); or the gusset may be formed as shown in Fig. 7. This is a most efficient arrangement, for the capabilities of the gusset are greatly increased, and its exposed edges are well protected against wear and tear. The gusset plates are the same thickness as the stringer plate; they are usually 3 frame spaces in length, and extend $1\frac{1}{2}$ frame space out upon the beam.

Art. 103. The different forms of **side stringers** fitted **in conjunction with web frames** are shown in Fig. 1, Plate 7, and Plate 106. They are severed and jointed at each web. In construction they usually resemble the web frames themselves; the plate is of the same breadth and thickness, and the face angles may be identical. A large single face angle is usually adopted (Plate 106), both for the stringers and web frames; but sometimes the edge of the stringer plate is flanged (Figs. 7 and 10, Plate 7). The connection to the web frame is made by short lugs, and by a *diamond*, *gusset*, or *strap* face plate (shown respectively in Figs. 5, 10, and 12, Plate 7). The lugs may be double, one above and one below (Fig. 5), or a single large one may be adopted, having flanges 5 or 6 inches wide, to take two rows of rivets (Fig. 10). To secure a good connection they should be the full width of the web; and, to permit of this, the fore-and-aft stringer angles must be cut short. The fitting of these lugs is sometimes carelessly done; the rivets through the web frame (particularly those in the shell and face angles) may be so much out of position as to fall on the toe or heel of the lug, and as they pass through four or five thicknesses they may be unsound. The continuity of the stringer face bars is made good by the diamond, gusset, or strap face plate; when a single face bar is adopted, a gusset or face strap is preferred to a diamond, for the flush upper surface of the stringer is then maintained right up to the web. The size of a diamond, gusset, or strap face plate varies with the depth of the web frame; the thickness of the last is greater than that of the other

two. If only the fore-and-aft strength of the face bars were considered, a simple parallel strap of the sectional area of the face bars might suffice, but the diamond or gusset formation has a useful clamping effect, giving rigidity to the joint in all directions. Lloyd's rules now permit of the strap formation shown in Fig. 12, the efficiency of which is superior owing to the rivets being distributed with due regard to securing continuity of strength in the severed face bars. At the bulkheads half diamonds or gussets are sometimes fitted, one on either side, connected by a short vertical angle or flange; but it is better to fit a horizontal bracket here, for then both the stringer and bulkhead receive useful support (Fig. 9, Plate 23). If the breadth of the side stringer is as great as 18 inches, and its span between web frames exceeds 8 feet, it must be supported and held to its work midway between the webs by a bracket, placed either above or below (Fig. 11, Plate 7).

Art. 104. In order that the strength of the **side stringers and keelsons** may be maintained uniformly throughout, Lloyd's rules specify, in a general way, that they shall pass **through the transverse bulkheads**, the watertightness of the latter being secured by fitting angle collars around the former (Fig. 7, Plate 22, and Figs. 11 to 14, Plate 55). The work of fitting and caulking these collars is a small matter so long as the stringers are merely double angle bars; if of less simple section, however, it is usual not to pass them through the bulkheads, but to stop them on either side, so as to avoid extensive watertight collaring; in which case the continuity of the stringer is made good by **large bracket plates**, having a double-angle or large single-angle connection to the bulkhead (Figs. 9 and 10, Plate 22, and Figs. 8 and 9, Plate 23). When the stringers are of the massive kind adopted with deep framing, Lloyd's rules require these brackets to be twice the depth of the stringer within the face bars, and $\frac{1}{20}$ inch thicker, and that they shall be connected thereto by a double row of rivets. In any case, whether or not those extra-strong side stringers (and the wide stringer fitted in conjunction with widely-spaced hold beams) pierce the bulkheads, Lloyd's rules require large gussets to be fitted to distribute the support given by the bulkhead to the vessel's side (Fig. 8, Plate 9). In cases where they have not been fitted, the resulting concentration of stress has led to loosening of the riveting in the vicinity of the bulkhead. In the bulkheads of oil steamers, where absolute oil-tightness is essential, it is usually preferred to sever all side stringers, and the keelsons as well, connecting them to the bulkheads by brackets. And the latter are made very large, so that in addition to maintaining the full strength of the fore-and-aft parts, the bulkheads may receive ample support (Figs. 10 and 11, Plate 26). And, further, in oil vessels the shell lugs of intercostal stringers are doubled in the neighbourhood of the bulkhead, or all fore and aft in large tanks (Fig. 11).

Art. 105. The **number of side stringers** specified in Lloyd's rules refers to the 'midship portion of the hull; as regards the end portions, where, owing to the sheer, the depth of hold may considerably exceed that amidships, it is required that the distance between the stringers shall not be greater than it is amidships. To comply with this, in vessels having a double bottom, an additional stringer must be fitted at the fore end, as shown in Plate 10. As a vessel's girth at the ends is less than it is amidships, it follows that in vessels not having a double bottom, if the side keelsons and stringers were all extended to the stem and stern, they would approach one another too closely; this is avoided by stopping the side keelson some distance from the ends. At the stem and stern, where the stringers of opposite sides meet, they are connected by V-shaped gusset

plates, termed "**breast hooks**" (Plate 10). Those at the stern are more particularly referred to as "**crutches.**" Breast hooks are useful in that, by holding fixedly the ends of the stringers and uniting the vessel's sides immediately abaft the massive stem bar, they increase the strength and rigidity of the stringers and of the bow generally.

Art. 106. End-on collision at sea, with other vessels or icebergs, is a contingency to which all vessels are liable; but as the forces brought into play may be quite irresistible, it would evidently be impracticable and inexpedient to endeavour to provide against them by giving enormous strength to the bow structure. In **warships** the injury which a striking vessel inflicts on the one struck is an important means of offence, and in their design is always kept in view. Practically all warships are designed with the familiar **ram bow**, the projecting under-water spur of which is well calculated to do a maximum of injury to the enemy, and a minimum to the attacking vessel (Fig. 2, Plate 31, and Fig. 2, Plate 84). The power of ramming, if exercised at all, would only be so at low speeds; even then, the stresses arising from sudden interference with the momentum of so large a mass would be very severe, and, consequently, in the design of a ram bow the greatest care must be observed to secure exceptional strength. Not only must the backward thrust due to the sudden stoppage of the ship be provided against, but also the subsequent wrenching or side-twisting effects due to the motion of the vessel struck. The latter effect usually accompanies end-on collision, and its consequences are often more serious—to both vessels—than those due to the first blow. To resist the backward thrust, the stem is made immensely strong, the shell plating immediately abaft it being doubled in thickness and rabbeted thereto; also, the internal framework is very massively constructed, thick breast hooks being introduced to tie together the sides and back up the stem. Formerly ram stems were sharply formed, the spur portion, though measuring several feet fore and aft, being only a few inches across; to give it, therefore, the necessary transverse strength, a horizontal ram—a massive slab-like breast hook—was fitted in line with the spur. Now, since it has been realized that the bow or forward end of a submerged body may, without increasing the resistance, be exceedingly bluff or full, the spur is made several feet wide, so that, being spherical or bulbous in form, it possesses great lateral strength (Fig. 2, Plate 84).

In **merchant vessels**, although **end-on collision** is only provided against in very minor degree by strength of bow, its dangerous consequences are most efficiently met by the introduction of a **collision bulkhead,** for when the bow collapses this takes the place of the damaged side, forming, temporarily, the watertight skin of the ship (Plates 10 and 20). To be useful, the bulkhead must, of course, remain intact, a condition depending on its distance abaft the stem and the extent to which the bow is likely to crush up. The greater its distance from the seat of disturbance, the smaller is the chance of its being injured, and in practice Lloyd's requirement of one-twentieth of the vessel's length is generally accepted as a minimum fairly compatible with safety. While not endeavouring to build the bow so strongly that it will withstand collision, the strength usually provided is sufficient to limit the damage to the portion before the bulkhead. Many cases are on record, of collisions at high speed with icebergs or other vessels, in which, although the bow has been crushed back, almost to the collision bulkhead, this has remained intact and saved the ship.

The stringers and connecting **breast hooks** are valuable in strengthening the bow against collision, the latter, by rigidly uniting the flexible side plating abaft the massive stem bar (Plate 10), effect a transmission of

the first shock over a considerable fore-and-aft portion of the bow. As a result of minor collisions, when the stem bar receives an oblique blow, it folds readily over, the thin shell plating on the one side crinkling up concertina-fashion, and on the other bending over with the stem. The breast hooks, by uniting the two sides just abaft the stem, are most capable in resisting such distortion. The upper part of the stem is well backed up by the decks, the stringer plates of which form excellent breast hooks. Below the lowest deck, Lloyd's rules require breast hooks to be fitted not more than 4 feet apart vertically; and in large vessels (over 24,000 plating numeral), to give rigidity to the upper part of the stem, commensurate in some degree with the weight and possible momentum of the hull, an additional breast hook is required between each deck, thus placing them at about 4 feet intervals throughout.

To support the stem bar properly, the breast hooks should, of course, abut upon it; and to give the greatest stiffening effect to the thin shell plating, they should be directly connected thereto. The lower breast hooks usually stop at one of the deep floors, some distance from the stem, for to fit them right up to the latter would result in inaccessible spaces below. The deep floors, of course, by tying the sides together, dispense in some measure with the necessity for breast hooks. At the stern, only such crutches are fitted as are required to unite the ends of the stringers; and in steamers the deep floors required at this part usually take their place, the stringers being bracketed to the after-peak bulkhead. Lloyd's rules require the breast hooks to be the thickness of the 'midship floor plates. When the free edge is wide it should be stiffened by an angle bar or flange (Fig. 7, Plate 10). Sometimes the plate is cambered to suit the "lie" of the stringers which it unites, but it is evidently better that it should pass straight across.

Art. 107. The sides of the hull **at the bow** are liable to special **stresses of a collapsing or panting** nature. These occur as a result of violent pitching in heavy weather; for, with the bow one moment deeply submerged and the next raised quite out of the water, the consequent alternation of intense pressure with no pressure at all tends to make the sides move in and out, or **pant.** The collapsing pressures may be very intense, for not only are they caused by the steady pressure of deep immersion, but by the dynamical effects of the vessel's movement, *i.e.* the forward motion of the hull combined with the downward plunge of the bow against advancing waves. The intensity of the shocks depends much on the vessel's trim and on the design of the hull. Modern, full, cargo vessels, when in ballast, float so lightly on the water that, should they encounter heavy weather, such as occurs in the North Atlantic in winter time, the fore end may lift so high and plunge with such violence against advancing waves as to suffer shocks of a most intense character, tending to collapse the sides and damage the bottom in way of the fore foot. When the vessel's sides at the bow are full or rotund, they are not likely to receive blows so forcible as when they are flat. Further, when of the former type the structure is naturally better able to withstand severe pressures, for, being rounded like an arch, local collapse must involve widespread straining over a large area; a flat surface, similarly stiffened, might yield to a comparatively small pressure.

Sailing-ships are more liable to suffer from **panting stresses** than steamers (except the latter encounter heavy head seas when in light trim), for their bows are usually flatter, and, being shorter, they are more liable to pitch. Also, as they are constantly heeled over, the panting pressures are not equally intense on both bows, for as the lee one presents a more

directly opposed surface, it receives more severe concussions. The panting tendency is, therefore, one-sided or unbalanced, so that the *panting beams* specially fitted at this part do not neutralize it so well as when the pressure is equally intense on both bows.

The **straining effects of excessive panting stresses** are confined to the under-water bow, before and abaft the collision bulkhead, and are exhibited by loosening of the rivets in the shell and framework, and in the brackets connecting the lower ends of the side frames to the tank margin plate. The panting beams act as rigid struts between the two sides, and as they offer direct resistance to the collapsing pressures, the rivets uniting them to the frames are liable to suffer; in some cases they have been completely shorn. This is avoided by providing a stringer plate and large gusset plates on the ends of the beams (Fig. 3, Plate 10). The juxtaposition of rigid and flexible parts, by causing localization of stress, is a common source of weakness. The collision bulkhead, for instance, forms a stiff diaphragm between the flexible sides, and as a result of its peculiarly rigid resistance, should any of the rivets in the immediately contiguous framework or shell lack solidity, the abnormal local stresses may be most effective in bringing to light their latent weakness. To avoid such local straining, care must be taken to taper off the excessive rigidity of the bulkhead by fitting bracket plates to the fore-and-aft stringers; and similarly with the panting beams (Fig. 2, Plate 10).

The **provisions** usually made **against panting** are the introduction of one or two *additional tiers of beams* in the fore peak, and one or two (or more) beams in the fore hold, abaft the collision bulkhead (Plate 10), and by the reinforcement of one (or more) of the side stringers, by the addition of a wide plate to the double bars ordinarily composing it, thus making it a *panting stringer*. The necessity for these reinforcements is emphasized by the circumstance that, owing to the inward curve of the bow, the distance between the frames, measured on the shell, may be from 10 to 20 per cent. greater than elsewhere, and, as the frames are sharply bevelled at this part, they are less well disposed to resist deflecting stresses. Each frame has, therefore, not only a greater area of side to support, but is less efficiently disposed for the work. In large vessels, whose frames are widely spaced, those at the bow are sometimes placed closer together.[1] In others they are doubled below the lowest deck by an additional shell angle, and in large high-speed vessels web frames are introduced at this part. In large vessels the connection of the frame brackets to the tank margin plate is reinforced at this part by using double, in place of single, connecting angles, and by gusset plates. In sailing-ships specially extensive provisions are required against panting.

At the **stern, panting stresses** are usually unimportant. Those at the bow are due, in great part, to the forward motion of the vessel against advancing waves, whereas at the after end this influence tends to diminish them. In large sailing-ships one or two additional panting beams may be introduced, but the ordinary side stringers, when well connected by crutches, are usually sufficient. In steamers, panting stresses at the after end are well met by the after-peak bulkhead and the specially deep floors abaft it. Straining of the riveting of the framework and shell within the after peak is sometimes observed, but this is usually due to the vibrating effect of the propeller (Arts. 87 and 115). The sides of the hull at the stern, being almost vertical, meet with little concussive effect from the vessel's pitching movements. Above water, however, the opposite conditions prevail. The

[1] By the rules of the British Corporation, though the frame spacing may exceed 24 inches, this is the maximum allowed at the bow.

overhanging counter, being almost horizontal, may sometimes receive severe blows from the sea. The structural reinforcements here introduced, also those required at the bow, above water, are noticed in Art. 84.

Art. 108. There is **another class of panting stress** distinct from those just noticed. They occur as a consequence of encountering **head seas when in light trim.** The fore-foot of a long vessel, when in light trim, skims the surface, so that it encounters advancing waves with a series of impingements. When the surface of a fluid is struck flatly, it responds almost like a solid, and similarly with the flat part of the fore-foot as it meets advancing waves. To those on board, the shocks so received by the hull may be so violent as to make it difficult to stand on deck; they resemble those which might occur from the vessel striking a solid body. An instructive example of this wave-pounding action occurred in the case of the Russian circular yacht, *Livadia*. The features of this vessel are familiar; her draught was small, and her bow was formed by a gradual curving up of the bottom. On her maiden voyage, across the Bay of Biscay, she suffered serious injury, and, making water, put into port, when it was found that the shell plating under the bow was indented and cracked, and the framework distorted.[1]

These peculiar effects are practically only noticed in **modern vessels of full form,** particularly in those having a **flat or spoon-like fore-foot.** Cases of damage are often observed in such vessels after crossing the Atlantic in light trim in stormy weather. The region affected is the bottom of the hull just abaft the collision bulkhead. Usually the results are limited to fractured cement, loosened riveting, and indented shell plating, the frames showing up in distinct ridges. Only two or three strakes next the keel are affected, and, as a rule, only for a short fore-and-aft distance. In more pronounced cases the frames and floors may be bent and broken. The character of the injuries is often such that it is hard to believe they have been caused by sea action; they resemble what might be occasioned by running ashore bow-on, or by striking sunken wreckage, and formerly this was sometimes erroneously assumed as the cause.

Small **coasting vessels,** which have their **machinery at the stern,** and whose fore-foot when running light is, therefore, nearly out of the water, are also liable to a similar wave-pounding action, and, in their case, even in moderate weather. In these small vessels, when running light, it is almost impossible to keep a steady course against head seas, for the bow, having no grip of the water, swerves constantly to port or starboard. To improve the navigable qualities, and avoid at the same time the damaging effects just noticed, they are usually provided with a fore-peak trimming tank. But although the filling of this, by securing a more even trim, may remedy these evils, the concentrated load at either end of the hull, elsewhere light and buoyant, may, by causing violent pitching, give rise to straining tendencies equally serious. An additional feature of this continued wave action in these small vessels is the marked corrosion which occurs in the lower caulking edges of the plates and the contiguous rivet points in the vicinity of the fore-foot. This is, no doubt, due to the fact that the outward and upward rush of the water, and the blow struck by the vessel's fore-foot as it plunges into and against the waves, causes sufficient panting pressure on the thin plating of the inner strakes as to start the caulking of the landing edge, strain the riveting, and admit water into the joint. As

[1] An interesting account of the voyage will be found in a paper by Sir E. J. Reed, and also one by Capt. Goulaeff, in the *Trans. Institution of Naval Architects*, 1881. Sir E. J. Reed says, "and much more rarely, but still repeatedly, the blow would seem to be just such as one would expect to happen from the ship striking a rock."

proving this, it is found that when the strakes are arranged clinker fashion, with the caulking edge upwards, the above effect is not observed. It may also be due in some measure to eddies and the admixture of air with the water, a similarly rapid wasting effect being often observed in the caulking edge of lapped shell butts, and in the plating and riveting of rudders (Art. 270).

Lloyd's rules now require special provision to be made against the above stresses. In vessels which are of full form at the fore-foot, or whose tonnage coefficient exceeds ·78, all the frame angles between the collision bulkhead and one-fifth the length from the stern must be doubled within the double bottom (Fig. 1, Plate 10), or from bilge to bilge where there is no double bottom, and additional intercostal keelsons must be introduced. In vessels having a cellular double bottom with floors on alternate frames, every frame at this part must have a floor, or the longitudinals must be more closely spaced (Plate 88). Further, the 'midship thickness of the two strakes of shell plating next the garboard strakes must be maintained to the bow. The shell-to-frame rivets must be $5\frac{1}{2}$ in place of 7 diameters apart, and those in the landings 4 in place of $4\frac{1}{2}$ diameters. The strengthening effect of double frames is noticed in Art. 67.

CHAPTER X.

Art. 109. The thickness of **shell plating** suitable for any particular vessel is not one that can be decided by mathematical reasoning; like the scantlings of other parts of the hull, the thicknesses adopted in practice represent what experience has indicated as necessary. Nevertheless, the various matters which govern it may be readily stated, so that, with a knowledge of their influence, theoretical investigation may be usefully applied to corroborate the deductions of experience and give greater assurance in doubtful cases.

The first **duty of the shell** is, of course, to act as a *watertight skin*, and it must also give to the hull *longitudinal strength* and *general rigidity*. The former duty is unique, and cannot be shared; the latter may be largely performed by other parts. Longitudinal strength may be secured by plated decks, and by the stringers and keelsons; and general rigidity by these incorporated with the transverse framing, and by the transverse bulkheads. How thick the shell plating should be, therefore, may depend very considerably on how much these other parts contribute to the general strength.

As regards longitudinal strength, the shell is the most important part; being one large, continuous, well stiffened surface, all stresses acting in its plane are instantaneously transmitted, so that every part of it gives a simultaneous resistance. A deck may likewise be most capable; the upper deck, indeed, may be regarded as a horizontal continuation of the shell, homologous with the bottom plating. A deck, however, is usually of comparatively thin plating, and may be wanting in the lateral rigidity and fairness of surface essential to an efficient resistance of fore-and-aft stresses (Art. 12). Keelsons and side stringers are isolated and detached, and so may not, under fore-and-aft stress, co-operate simultaneously and assist the shell to their full power.

Art. 110. Notice, for a moment, some theoretical matters in connection with the behaviour of the shell plating, when, as a watertight skin, it resists pressures from without, tending to bulge it inwards between the frames. It is, of course, essential that no palpable bulging should occur, for if it did the riveting and caulking would not long endure, and the cement on the bottom would not remain intact. The **resistance which the plating offers may be** of two kinds—**that of a beam with fixed ends, or that of a suspension chain.** This will be clear if an experimental strip of plating be considered, fixed beam-like between supports representing the frames, and deflected by a load, see Fig. 3, Plate 11. The strip is here depicted as resisting in the manner of a beam with fixed ends. Throughout the middle curve its lower edge is in tension and its upper in compression; elsewhere the stresses are reversed. As shown in the sketch the curvature is evidently exaggerated, for, were it so pronounced, the strip must have lengthened very considerably, and would therefore be in a state of tension

throughout; in such a case, instead of a double curvature, it would assume the single curve of a suspension chain, as shown in Fig. 4. The tension of a taut horizontal chain, carrying a weight, depends on how much it is allowed to sag. If perfectly horizontal, it would be infinite; if the sag were so great that the chain formed a double vertical one, it would only be half the weight of the load suspended. It is well known that neither a thread nor a chain cable can be stretched *perfectly* horizontal, for before this state was reached both would break by their own weight.

It is clear, therefore, that the kind of resistance which the plating offers to bending pressures depends on how great is the deflection; if the pressure were slight, causing only small deflection, it would be that of a beam (if it were that of a chain the necessary tension would be enormous), in which case the strength of the plating would vary as the square of its thickness, and inversely as its length—the frame-spacing. If now the pressure were increased, so also would the deflection become greater; the plating would begin to suffer tension throughout and to act like a suspension chain, taking a single curve with a sharp knuckle at each frame.[1] After stranding, it is common to find the bottom plating set up, or corrugated, as shown in Fig. 6, Plate 3, its final resistance having been that of a suspension chain. The deformation is permanent, owing to the elastic limit of the material having been exceeded at the sharp knuckles at the frames. That severe tension has prevailed is sometimes shown by the circumstance of the frame rivet holes becoming slightly oval, or by the tearing of the plate in their line.

The foregoing assumes the plating to be perfectly flat; towards the vessel's ends, where it is convex, it has practically no tendency to bulge inwards; here it resists pressures like an arch, with little stress on the material. Where the side is concave or hollow, the large natural deflection between each frame enables the plating to give, at the outset, a powerful chain-like resistance. It should be observed that an experimental strip does not represent the case of a wide surface of plating, for when the latter is subjected to a local deflecting pressure, the part directly affected derives great assistance from the contiguous plating on either side, not similarly affected; it would have to bend both transversely and fore and aft. In increasing its resisting capabilities, such side support—supplementary to that of the frame—is very important; it is afforded in very perfect fashion by the intercostal shell connection of the keelsons, etc. With perfectly flat plating there must, however small the pressure, be some small deflection between the frames. In vessels drawing many feet of water, it is probable that, in the case of the bottom plating, it might be perceptible, *i.e.* if there were no cement, for this, when thick, confers great rigidity.

Art. 111. In the case of **large and long vessels** the shell plating is particularly called upon to supply the necessary **longitudinal strength.** Here, therefore, its thickness is practically governed by this requirement; and so, in assigning it, the simple girder theory may be kept in view, or applied as a useful means of comparison with other vessels of proved strength. In such vessels a thickness of plating sufficient to satisfy the requirements of longitudinal strength is usually ample as regards general rigidity. In **small vessels** on the other hand, longitudinal stresses are

[1] This interesting subject was investigated by Mr. Yates (*Trans. Institution of Naval Architects*, 1891). He deduced certain practical conclusions; amongst others, that, so long as the deflection did not exceed one-fourth the thickness of the plating, a beam-like resistance would cause the lesser stress on the material; but, if greater, the stress would be less when the resistance was that of a suspension chain. Also, see the late Mr. Read's paper on bulkheads, *Trans. Institution of Naval Architects*, 1886; and that of Professor Elgar, *Trans. Institution of Naval Architects*, 1893.

unimportant, so that a thickness of shell plating, ample in this respect, might be insufficient as regards general rigidity and local stiffness. The plating must be sufficiently strong to resist the buoyant pressure of the sea without any perceptible tendency to bulge inwards between the frames; in theory, therefore, if the frame-spacing were suitably reduced, its thickness in small vessels might be reduced to the minimum requisite for longitudinal strength. In practice, however, it must be sufficiently stout to withstand the bumps and blows of active service; in case of grounding, for instance, or bumping against quay walls, if the plating were too thin it would be too readily indented, or it might suffer such tension as to strain the riveting, or break through the adjacent line of frame rivet holes. Of course, a close spacing of the frames in small vessels might permit, to a certain extent, of thinner shell plating; for the frames would contribute a larger share of the necessary structural rigidity, the plating would be less liable to deflect between them, and its capabilities in resisting fore-and-aft compression would be increased. But for economical reasons a wide, rather than a narrow spacing, is usually preferred, for with fewer parts the cost of construction is reduced.

With so many interdependent and varying influences to consider, it would clearly be impracticable to attempt to decide, by mere theoretical investigation, what, in different vessels, should be the precise **thickness of the shell**, and what the proper spacing of the frames. The thicknesses and frame-spacing now generally adopted—and with satisfactory results—were determined, for the most part, by trial and error, *i.e.* by observing carefully the capabilities and endurance of different vessels in active service, noting in each the prevailing conditions, and making intelligent deductions from any abnormal effects. In the **early iron vessels** the shell plating was very thick, and the frames massive and closely spaced. At that time there was no current experience of the capabilities of iron as a structural material, and it was natural, having in view the possibilities of corrosion, that in fixing the scantlings the error should have been on the safe side. It was soon observed, however, that the strength was in excess, much exceeding that possessed by wooden vessels, and so the plating was reduced in thickness, and the frames were made less massive and placed wider apart. In the first table of scantlings for iron vessels, published in Lloyd's rules for 1855, the thickness of the shell plating required for a first-class vessel of 2000 tons was $\frac{14}{16}$ inch; and the frames were 6 by 4 by $\frac{10}{16}$ inch, spaced 16 inches apart. At the present time, in an iron vessel of similar size, the shell would be $\frac{11}{16}$ inch, and the frames 5 by 3 by $\frac{8}{16}$ inch, 24 inches apart (for steel, substitute 20ths for 16ths). In the early vessels the bottom plating from the keel to the upper turn of the bilge was made thicker than that above. Because it was anticipated that this part would suffer more from corrosion, for not only was it subject to the action of bilge water within, but was constantly submerged without, and, further, in the event of grounding, it was liable to abnormal local pressures. Later, however, when cement was universally adopted as an inside covering, it was seen that it was the plating on the vessel's sides that suffered the most, for here are present the conditions most favourable to corrosion—heat, air, and moisture. The bottom plating, always under water, suffers little, and not at all on its inner surface where covered by cement (Art. 462). With this greater experience, the practice of making the side plating thinner than that of the bottom was discontinued.

Art. 112. The shell plating is arranged in fore-and-aft strips, termed "strakes." There are three distinctive methods of disposing them, so as to connect each one to its neighbour. These are shown in Figs. 9, 11, and

12, Plate 11, and are known as the "*in-and-out*," the "*clinker*," and the "*flush*" or "*edge-on-edge*" system. In the early iron vessels the clinker system was commonly adopted, but it soon gave place to the now universal in-and-out method. The flush system is principally confined to yachts, where the handsome appearance of an unbroken, smooth surface may be desired.

By the **in-and-out system** alternate strakes—the *inner*—fit close, or *fay*, upon the frames, while the *outer* (unless they are joggled as shown in Fig. 10, Plate 11) are distant therefrom by the thickness of the inner. To fill the vacancies between the frames and the outer strakes, strips of iron, termed "*liners*," or "*packing*," are introduced. The overlap of contiguous strakes is termed the "*landing*," and the edge of the plate, visible on the outside, the "*sight*," or "*caulking edge*." In the actual work of fitting the plating on this system, any or all of the inner strakes may be fitted at any time, and, as is not uncommon, be riveted to the frames before the outer ones are dealt with.

The **clinker system** requires the strakes to be fitted consecutively like the slates of a roof; it involves double the number of frame liners, and, instead of mere parallel strips, each one must be tapered. Apart from the extra labour and expense in making and fitting the liners, the work, when done, is seldom perfectly satisfactory. A parallel liner of proper thickness fits accurately, with solidity throughout; when tapered in the usual rough way under the steam hammer, the taper may be irregular and imperfect. Also, the frame rivets are of unequal length, a circumstance which is an inconvenience in the riveting work. In the early days of iron ship building the necessity for uniform and solid contact between the frames and the shell was not at first realized, and sometimes, instead of liners, small iron washers were employed, one for each frame rivet. With the clinker strakes then in vogue this saved the work of making tapered liners; but, of course, the union of frame to shell was very imperfect; in the absence of frictional contact between the surfaces, straining and leakiness of the rivets was almost inevitable. The classification societies require all liners to be in one piece, *i.e.* not in short lengths, and not made up of several layers. Having the above disadvantages, the clinker system is no longer employed; in most vessels, however, portions of the shell are so arranged. If there is an odd number of strakes, for instance, one of them may have to be disposed clinker-fashion (Plate 100); and similarly in the case of a *stealer*, which, as described later, takes the place of an inner and an outer strake (Fig. 1, Plate 11). Practical details in connection with frame liners will be found in Art. 527.

The **flush system** of shell plating is practically confined to yachts, and, being adopted for appearance' sake, it is usually limited to the plating above water (Fig. 12, Plate 11). The different strakes fit against one another, **edge-to-edge**, and are connected within by fore-and-aft strips, termed "*edge*," or "*seam strips*." As the strips are usually worked continuously, frame liners are required behind each strake; but if the less usual method is adopted of fitting them in short lengths between the frames, all liners are dispensed with. The latter plan is advantageous in that much three-ply riveting is avoided, and the weight of the liners and the work of fitting them saved. Nevertheless, the seam strips are usually worked continuously, for there is a general feeling that to cut them would be prejudicial. At the end of each short strip, where it butts against the frame, there would be a small point in the seam not backed up or covered; if the caulking became defective elsewhere, the entering water would meet the edge strip, so that rust, accumulating between, would soon restore watertightness; but if defective at a point not backed up, the water might pass through

unimpeded. Although, with bad work, this would be so, it is not a serious objection; shell plating is sometimes worked in this way, as also plated decks and tank tops, and with no ill consequences. It should be observed that at the butt straps of all outer strakes there are similar uncovered points (Art. 311). Of course, the severance of the seam strips at each frame does not tend to longitudinal strength, but in small vessels this is unimportant.

The flush system of shell plating is costly in workmanship, for to fit curved plates accurately, edge-to-edge, requires very considerable care and skill; if not in contact at any part, the unsatisfactory expedient is adopted of inserting slips of iron. As noticed in Art. 321, the perfection of the caulking of a butted joint is less assured and less permanent than that of a lapped one; also, compared with an overlap, an edge-strip connection involves double the amount of riveting. When well fitted, however, edge-to-edge plating has certain structural advantages; for the mere circumstance of the seam strip having twice the breadth of an ordinary landing, gives to the surface considerably more lateral stiffness. Further, when exposed to stresses acting in its own plane, a flush surface is a more rigid one; with lapped seams, any force tending to push one strake over the face of its neighbour tends to shear the rivets; when the edges abut, the rivets suffer no stress, the plates are locked, as it were, independently of the riveting. The tendency in the rivets of an overlapped joint to sheer is often illustrated in the case of those connecting the frame angles to the floors; as a result of severe upward pressures through grounding, or the special panting stresses noticed in Art. 108, the rivets are often loosened or shorn. In the case of the shell plating, vertical stresses, tending to force each strake over its neighbour, occur with every hogging or sagging tendency (Art. 302). These are mostly felt in the landings towards the bow and stern, about the middle of the vessel's depth, and in large vessels (over 480 feet) Lloyd's rules now provide against them by requiring that the landings at these places shall be treble riveted.

At one time, when cost of construction and weight of hull were not so much considered as now, the **shell plating** was sometimes **arranged edge-to-edge throughout,** but in place of fitting narrow seam strips within, they were placed outside, and were made wide, about half the breadth of the strakes they covered; the appearance outside was, therefore, that of in-and-out plating, but half of the entire surface was of double thickness (Fig. 13, Plate 11). The s.s. *City of Rome* was built on this plan; but, in the case of the topside and bilge plating, the outside or covering strakes were also fitted edge-to-edge, giving a flush surface and a double thickness throughout. At the period of her construction she was of unprecedented size, and so the question of longitudinal strength was a prominent one; being built of iron, with comparatively small plates, the plan of systematically doubling all the topside plating was an excellent one. A similar method is advantageously adopted in some of the largest modern Atlantic liners.

Art. 113. In order to dispense with frame liners, the **shell plating** is now very commonly **joggled,** as shown (Fig. 10, Plate 11, and Plate 102). The inner strakes are fitted in the usual way, and the outer ones, overlapping them, are bent sharply inwards, or joggled, so as to fay upon the frames. The advantages are obvious; the weight of the liners is saved (about 25 tons in a vessel 330 feet long), so that the dead weight carrying capacity is at once increased by that amount; nearly all three-ply riveting is avoided, and there is direct and perfect contact between the shell and frames; also, the work of fitting the liners is saved, but there is, of

course, a little extra work in joggling the plates. The joggling is done in a special machine (Fig. 3, Plate 95). Each margin of the plate is passed between revolving drums, so formed, with raised and sunken portions, as to give the necessary impress or joggle; when necessary, the joggling may only be done locally. The end joints may be lapped and machine tapered in the usual way. This system originated in the well-known *turret-deck* type of steamer, but its application is now common, not only for the shell, but for deck and tank-top plating.

Another method of avoiding frame liners, now commonly adopted, is to **joggle the frames** instead of the plating, so that they may fay against the outer strakes (Plate 103). The joggling is done cold, in a hydraulic press, before the frames are bent. As regards the side frames, this system is but little employed, and only for those frames which have little or no bevel, but its use is fairly general for other parts, such as the light-scantlinged frame angles and reverse bars within a double bottom (Plate 106). By this method the plating looks better than when joggled, for by the latter system the landings are conspicuous and rather unsightly; and it is advantageous in that repair work may be more easily effected, for few repairing establishments have a plate-joggling machine, whereas an angle bar may be readily joggled, or liners may be introduced locally in the usual way, without prejudice to the appearance of the plating. Sometimes, however, the joggling is imperfectly performed; the heel of the bar may not be properly set down, and the joggle may be either too deep or too shallow, so that liners must be fitted to fill the vacancies.

Art. 114. Excepting the garboard and sheer strakes, the **shell plating** amidships is made of **one general thickness.** The sheer strake is thicker, because, forming the upper margin of the shell, it is exposed more than any other part to severe stresses of tension and compression; and the garboard strakes, because, lying close to the keel, they are specially exposed to local pressures through docking and grounding; also, when united to a massive bar keel, they are directly called upon to assist it in its duty as a rigid backbone to the vessel's bottom, and as they are connected thereto by large rivets, thickness is very desirable. When subject to longitudinal bending stresses, the hull is less severely tried at the ends than at the middle, and, accordingly, the shell plating, like all other parts, is **reduced in thickness towards the bow and stern.** If the girder theory alone were considered, the plating at the extreme ends might be made very thin; in practice, however, the reduction is seldom more than 20 or 25 per cent., for, as already noticed, the shell has other duties than merely to give longitudinal strength; it must resist blows struck by the waves and impingements with quay walls or other vessels in harbour; and, being riveted to the massive framework within, it should, for the general rigidity of the structure, be of appropriate thickness.

The **thicknesses of plating** suitable for vessels of different sizes are **tabulated in Lloyd's rules** (see Plate 4). In the case of the garboard and sheer strakes, as they are of special thickness, a minimum breadth is also given; this, however, being small, is usually exceeded in modern vessels. With plates varying in thickness by twentieths of an inch, it would, of course, be impracticable to increase uniformly the shell in the same gradual way that a vessel's dimensions might vary (Art. 44). In practice, however, a sufficiently gradual increase is secured by adding perhaps $\frac{1}{20}$ inch to the thickness of one strake at the bilge; or, in a considerably larger vessel, one, two, or three bilge strakes, and the sheer strake might be thickened; or a general increase made by adding $\frac{1}{20}$ inch to every alternate strake. When alternate strakes are of unequal thickness, the

outer are made the thicker; compared with the inner, they are somewhat less efficient, for they do not lie in actual contact with the frames (except they be joggled), and when their joints are butted, the straps do not entirely cover them. Also, as they take all contact with quay walls, etc., they form *rubbing strakes*, so that, when the paint is scraped off, they are particularly exposed to corrosion. In old vessels their edges are sometimes so worn away as to require the renewal of the plates. The full thickness is maintained over the 'midship half length, gradually tapering thence towards the ends. In view of the special duties of the garboard strakes, they do not usually taper more than $\frac{1}{20}$ inch.

Art. 115. At special places, to give local strength or stiffness, **the shell** is either **increased in thickness or doubled.** In steamers over a certain size (16,600 plating numeral), all plates connecting to the stern-frame are made the full 'midship thickness. In small vessels the bossed plates in way of the propeller shaft are of 'midship thickness; when over a certain size (13,900 plating numeral) they are $\frac{1}{20}$ inch thicker; and in still larger (over 26,500 plating numeral) they, as also the contiguous ones above and below, are made $\frac{2}{20}$ inch thicker. This increased thickness is necessary to minimize the straining effect of the vibration from the contiguous propeller; it gives massiveness and rigidity to the structure at the point where the shaft, the vibrating medium, takes contact with the hull. Owing to their sharp and irregular curvature, the boss plates are difficult to fit; they do not, therefore, always lie in perfectly close contact with every frame, and so tapered liners are often introduced. For this reason, and on account of the inaccessibility of the interior of the hull at this part, the riveting of these plates is not always perfect, and defects, even if slight, readily declare themselves by loose rivets. To avoid such straining—which is difficult to remedy owing to the presence of the shaft tube within the hull—the plates are not only thickened, but their joints are more securely riveted, treble instead of double, or, if butted, double straps are employed. In vessels having a **double bottom,** the inner one, by sharing in all longitudinal stresses, may greatly relieve the outer, and, in view of this, as also of the mere duplication, it is usual to **reduce the thickness of the shell at this part** by $\frac{1}{20}$ inch. This reduction, however, is only made when the plating is thicker than $\frac{1}{2}$ inch, otherwise, it might be insufficiently stiff under local pressures. Further, no reduction whatever is made where the floors in the double bottom are only on alternate frames, for as the plating in such cases is less well supported, its thickness and stiffness must be maintained. Where, on account of the vessel's proportions or other features in her design, specially severe longitudinal stresses may be anticipated, the sheer strake is either thickened or doubled (Art. 14). If the vessel's length exceeds eleven times the depth, Lloyd's rules require it to be thickened by $\frac{1}{20}$ or $\frac{2}{20}$ inch. If twelve depths be exceeded, then, while in a small vessel it would be $\frac{2}{20}$ inch thicker, in a larger it might be doubled (Fig. 13, Plate 4), and an increase made in the thickness of the strake below. If in a large vessel (over 40,000 plating numeral) the extreme length of thirteen depths be exceeded, both the sheer strake and the strake below, as also the upper deck stringer plate, may have to be doubled. And similarly with the plating at the bilge, one or more strakes being thickened or doubled according to the vessel's proportions. Such reinforcements are confined to the 'midship portion of the hull, for one-half to three-fourths of the length. As noticed in Art. 10, the sheer strake is always doubled at the ends of a bridge-house or long poop.

When circumstances require the **sheer strake** to be **doubled,** it is common, as an alternative, to thicken it and the strake below, as also the

upper-deck stringer plate, all to such an extent as to give the required additional sectional area (where there is a long bridge house or shelter-deck superstructure, its side plating is usually thickened as an alternative to doubling the sheer strake in way of it). Theoretically, as the sheer strake (in a flush-deck vessel) is the highest part of the hull, it is here that all reinforcing material should be placed; in practice, however, it is found that in large vessels straining effects are not always confined to the sheer strake; sometimes the strake below may show evidence of severe stress, while the sheer strake shows little or none. In a large, deep vessel the difference in the stresses which, according to the girder theory, the material of the sheer strake and of the strake below must simultaneously suffer, is small; consequently it may be more than discounted by imperceptible structural deficiencies. For instance, in the case of two adjacent strakes, it might happen that, through one of them lying more directly in the line of stress, it would be unfairly strained; or perhaps, owing to slight differences in the mechanical properties of the material, or deficiencies in the riveted joints, the one part, though subject apparently to the same or even a less stress than the other, might really be the more severely tried.

To thicken slightly two or more strakes in place of doubling one, is advantageous in that the cost of fitting the doubling and of much additional riveting is saved; and it avoids three-ply rivets, which, with thick plates, are not always reliable (Art. 306). The deck stringer and the strake below the sheer are not stiffened, like the latter, in the middle by a continuous gunwale bar. To make them thick, therefore, is advantageous, in that they are then more likely to assume and retain a perfectly fair surface, and thus be more capable of simultaneous co-operation under stress. If a vessel's topside plating failed by excessive compression, the thick sheer strake, being rigidly held by the gunwale bar, would crush rather than bend, but not until the adjacent strakes had ceased to yield their proper share of the resistance. Beyond a certain stress, these comparatively slender and ill-stiffened parts would cease to increase correspondingly their resistance; if the compressive force were increased they would buckle between the frames, or await, with perfect readines to buckle, the later failure of the stiffer sheer strake. If now these less capable strakes were thickened, their tendency to buckle and shirk the stress would not supervene at so early a period; they would, therefore, assist the sheer strake, and take a fair share of the work under a much higher stress than formerly.

In cases where, to secure greater strength, a strake of plating is doubled, it might appear that the desired effect could be obtained more simply by employing a single plate of twice the thickness. This, however, is not so; for the joints are points of weakness, and, with ordinary hand riveting, the thicker the plates and the larger the rivets the more marked is the weakness likely to be. When in two thicknesses, only one-half of the material is jointed at one spot, and so any unavoidable loss of strength at each joint is reduced by half.

The term "**doubled**," currently used, does not always mean that the thickness is precisely doubled. The sheer strake, for instance, is thicker than the adjoining strake below, and as it is usually an outside strake, the doubling within is really an extension of the thinner strake below; to make it thicker would interfere with the contact of the latter with the frames, or necessitate special frame liners. According to the strength required, the sheer strake may be doubled throughout its width, or only the part below the deck may be doubled. The latter arrangement has the advantage of avoiding three-ply riveting all along the gunwale bar. In large vessels the total thickness of a double sheer strake may approach two inches, and when

so massive it becomes a question whether, when subject to severe stress, the ordinary gunwale bar, with a single row of rivets, would form a sufficient connection to the heavy deck stringer. In such cases a substantial increase in the connection is sometimes made by **doubling the gunwale bar** below the stringer, in short pieces between the frames (Fig. 14, Plate 4); otherwise, an extra massive single bar may be fitted, having double-riveted flanges, 6 or 7 inches wide. Such an attachment not only increases the efficiency of the parts, but minimizes any weakening tendency of the end joints (Art. 281). In vessels having a long bridge-house or shelter deck, it is now usual to build the latter so substantially that it may form the upper part of the hull as a girder, in which case, instead of doubling or thickening the sheer strake, the side plating (deck stringer, etc.) of the bridge or shelter deck, otherwise thin, is increased in thickness from 20 to 100 per cent. The sheer strake, in any case, is, of course, doubled at the ends of the bridge, where the sudden diminution in the depth of the girder and the stoppage of important longitudinal material would otherwise create a marked weakness.

At one time it was not uncommon to double one or two of the bilge strakes, now this is seldom, if ever, done, for it is costly in workmanship and of doubtful utility. In long vessels, where special longitudinal strength is required at the bilge, it may be obtained in ample degree by slightly thickening some of the strakes, and by fitting a substantial bilge stringer. There is little doubt that much of the **weakness** formerly thought to exist **at the bilge** was imaginary. The idea arose from a wrongful interpretation of certain effects. In wood vessels, longitudinal straining immediately proclaimed itself by opening of the butts, the different planks sliding upon one another. In the early iron vessels similar symptoms were often observed; the butt joints, originally closely caulked, soon gave signs of **apparent leakiness**, showing in dry dock as damp rusty streaks or crevices. Those of the bilge were usually the first to show; in course of time they opened or gaped just as if the plates were drawing asunder. The principal cause of these effects is noticed in Art. 297. That they are not always attributable to straining is evident from the circumstance that where, in two adjacent strakes, the joints of the one are lapped and of the other butted, while the former are unaffected, the latter may open as just described. Various matters in connection with the jointing of the shell are dealt with in Art. 297 onwards.

Art. 116. In vessels engaged in the Canadian or Baltic trade, the **shell plating at the bow** is frequently injured by impingement with **floating ice.** As a rule, the damage is limited to indentation of the plating, but in cases where the vessel is carelessly navigated—driven ahead through the ice—both the framing and plating may be forced in and broken. To provide against this, the bow plating is often doubled, from the stem to the collision bulkhead, in the region of the water line, making it a flush surface both inside and out. In other cases the frames may be placed closer together at this part. When lying at anchor in a tide-way, the rubbing or **chafing action of the cable** on the bow plating is apt to wear away the landing edges of the outer strakes; to avoid this, the inner strakes are sometimes doubled, so as to present a flush surface for the rub of the cable (Fig. 14, Plate 11); otherwise, as an alternative, bevelled strips may be fitted close to the landing edges (Fig. 15). When loading or discharging cargo, the ascending or descending packages may catch the landing edges of the side plating, to the prejudice of the plates, and the danger of those working below. To avoid this, the inner strakes of the topside plating are sometimes doubled immediately abreast of each hatchway; otherwise, bevelled strips may be fitted as just described.

Art. 117. When **coaling ports** are cut in a vessel's side, it may be necessary to make good the loss of sectional area or strength by doubling the plating immediately above them. Coaling ports are usually of small size, less than two feet square, and if they are situated well down, below the sheer strake, they may prejudice so little the longitudinal strength of the hull as not to call for special **compensation** (Fig. 3, Plate 60). Often, however, they are cut just below the sheer strake, and as here the plating may be subject to severe longitudinal stress, it is important, especially in large vessels, that the continuity of its sectional area should be maintained. In such cases, therefore, **doubling plates** are fitted above the port (Fig. 1). In awning and shelter-deck vessels, cargo ports or doors are sometimes cut in the side plating of the upper 'tween decks (Fig. 8, Plate 26, and Figs. 2 and 4, Plate 60); in which case, to provide sufficient compensation, it may be necessary to fit thick doubling plates above and below the port; and a web frame at each side, to make good the loss of transverse strength due to the cutting of the frame. And sometimes the stringer plate of the deck above the port is also doubled, which affords both longitudinal and transverse strength. As a short bridge house does not require such perfect continuity of strength, only partial compensation for openings in its side may suffice.

The sheer strake amidships should in no case be weakened by holes; it is often pierced by **sidelights**, and if these fall within three-fifths of the vessel's length amidships, it may be necessary, if the sheer strake forms the upper margin of the shell, to make **compensation.** Of course, so long as the sectional area cut away by the lights is not greater than that removed at each frame by the rivet holes, there is no loss of strength. Compensation for sidelights is usually provided by thickening the sheer strake by $\frac{1}{20}$ or $\frac{2}{20}$ inch, or by doubling the gunwale bar above the light; the added bar supplies the necessary sectional area, but, to be effective, it must be longer than one frame space (Fig. 5, Plate 60). To take the heavy shell riveting of the hawse pipes, and provide a rigid base of attachment for the pipe, the shell plating is either locally doubled or greatly thickened (Figs. 9 and 12, Plate 66). If it were thin, the cast-iron pipe might fracture under the severe stresses imposed by the cable when it is suddenly brought up when running out, or when the vessel surges at her moorings. Similar doubling plates are fitted on the thin bulwark plating in way of mooring pipes (Fig. 9, Plate 59).

Art. 118. In the early days of **iron** shipbuilding, the **shell plates** were **very small**; from 8 to 12 feet long, by 2 to 3 feet wide. Their size was limited by difficulties of manufacture; but now, with steel, the only limiting element is the capabilities of the shipyard machinery. **Steel plates** can be rolled of **almost any length,** 100 feet, or more (if narrow); their breadth dimension, however, is limited to 10 or 12 feet. For ship work, great breadth is not useful; for large boilers it is, and in some of these, plates 24 feet long, by 10 feet wide, by $1\frac{1}{2}$ inches thick, weighing over $6\frac{1}{2}$ tons, have been used. Length in the various plates of a vessel's hull is always desirable; the end joints represent transverse lines of weakness, and as their number, with long plates, is reduced, they may be more remotely disposed. Plates which, being straight and flat, do not require transverse rolling or furnacing, may be of great length; the largest actually used are 60 feet long by about $3\frac{1}{2}$ feet wide; they are employed for the 'midship portion of the shell and deck stringers. Plates so long, however, are quite exceptional, they are awkward to manipulate, and costly in the matter of labour; moreover, when the breadth of the strakes is limited, any greater efficiency which may result from a better disposition

of the end joints is small. Some first-class shipbuilding yards have machine tools capable of dealing with 36-foot plates, but in most cases 24 feet is the maximum length. In small shipyards the machine tools are not always modern, and in these, small plates, from 14 to 16 feet long, are still employed; for small vessels they are not unsuitable. As very short plates involve numerous contiguous joints, they are, of course, objectionable, and the classification societies, therefore, state a minimum length of about 12 feet. Some of the plates which connect to the stem and stern post may often be quite short, but in these length is unimportant.

To simplify the constructive work, it is desirable that the **strakes of plating** should be as wide as possible, for there are then fewer landings to rivet and caulk, and fewer plates to fit. But the **structural efficiency** of the hull **limits the breadth**; for, as noticed in Art. 281, each joint forms an unavoidable line of weakness, and the longer such line, the greater is its weakening effect on the hull. That this is so will be clear if the extreme case is imagined of a single strake so wide as to encircle the hull: here there would be no uniformity of strength; the end joints, extending from keel to gunwale, would form prominent lines of weakness; the hull might break in two by tearing one asunder, while between each joint the strength would be perfect. The hull, in fact, would resemble a thin stick, deeply notched at wide intervals. If now the opposite extreme be considered, of very narrow strakes, it is evident that with plates of the same length as formerly, the numerous joints might be so uniformly distributed that at no transverse section, more than another, would there be more joints or greater transverse weakness. It is in view of the above that the classification societies place a limit on the breadth of the shell strakes, about 56 inches, as a maximum. This is often exceeded, however, plates up to 6 feet in breadth being employed; but the efficiency of the joints is specially considered, by a good shift and increased riveting—quadruple, in place of treble.

Art. 119. As a vessel's girth is greater amidships than at the ends, it follows that the **strakes must taper in breadth.** As a rule, the topside strakes are only slightly tapered, for when parallel, or nearly so, the hull above water has a finer, smarter appearance. When the vessel's beam is considerable, and there is little sheer, the strakes, if they all extended to the stem, would become very narrow; in such cases, therefore, one or more are discontinued at some distance from the stem, in the manner shown (Figs. 1, 2, 5, and 6, Plate 11). This, of course, is advantageous in reducing the length of riveted landing edges and the number of plates, and it avoids crossings of the landings with the intercostal side stringers, with the awkward riveting which these occasion. A strake discontinued in this way is sometimes termed a "**drop strake**;" and the one taking the place of the two, a "**stealer.**" It is not always found necessary to drop strakes towards the stern, for here the width of the counter serves to maintain the girth. Sometimes, under the counter, the process is reversed (Fig. 8), a strake stopping short when it reaches the counter, and being continued by two or three narrower ones; an appearance of levelness in the upper landing edges at the stern is thus secured, and crossings of the landings with the second deck avoided. In some vessels all the strakes, from the gunwale to the upper part of the bilge, are made of parallel width throughout; so also are the strakes from the keel outwards, each one, however, terminating by abutting on the lowest strake of the first series (Fig. 7). When thus arranged, with wide strakes throughout, the number of plates and workmanship is reduced. In wood ships, the sheets of copper sheathing are all of one breadth, and are disposed in this manner.

Art. 120. Except in spar and awning-deck vessels, the **thickness of the shell plating** is practically the same from sheer to garboard strake. In vessels of spar-deck type, that of the upper 'tween decks is from 20 to 35 per cent. thinner. In awning-deck vessels the upper 'tween-deck plating, as also the side plating of deck erections—poop, bridge, or forecastle—is from 30 to 45 per cent. thinner than that below. In a quarter-deck vessel, built to Lloyd's rules, the sheer strake is continued from stem to stern without break; the strake of plating above it, in way of the quarter-deck, being $\frac{1}{20}$ inch thinner than the ordinary plating, if this is not less than $\frac{7}{20}$ inch (Plates 14 and 104).

The **British Corporation** do not specialize types, such as spar-deck, awning-deck, etc., nor do their rules regard deck erections as mere superstructures, but require them to contribute to the general strength of the hull, with thorough compensation for all openings in their side plating. By these rules, the thickness required for the **side plating of erections** varies with the length of the vessel and the relative length of the erections. In a vessel 500 feet long, for instance, having erections covering 90 per cent. of the length, or the whole length as in an awning-deck vessel, the thickness of the 'midship, or bridge-house, portion would be much the same as the ordinary shell, viz. 93 per cent. thereof; and that of the forecastle and poop portions 82 and 64 per cent. respectively. As noticed in Art. 10, a strong 'midship deck erection is an important means of strengthening the hull of a long vessel, and it is evident that the side plating of a forecastle, owing to its exposed position, may with advantage be made thicker than that of a poop. In smaller vessels, not requiring so much longitudinal strength, the side plating of the erections is relatively thinner, being only from 60 to 70 per cent. of the normal shell—according as the erection is short or long. By this society's rules it is required that the sheer strake of a quarter-deck vessel shall be raised to the level of the quarter-deck, scarphing, of course, with the remainder.

CHAPTER XI.

Art. 121. As noticed in Art. 37, the **beams** may be regarded from two points of view; as beams proper, and as struts or ties, connecting the vessel's sides rigidly the one with the other. Those of the upper deck may be regarded as horizontal continuations of the side frames; in combination with a plated deck they complete the tube-like formation of the hull. In cargo vessels of moderate size there is seldom a second deck; but, when over a certain depth, the sides of the hull require the intermediate supporting effect of a second tier of beams, which, being fitted merely as ties or struts, may be widely spaced, or suppressed entirely in favour of stronger framing. Whether or not a second deck is desirable as a platform for cargo depends on the vessel's trade. In vessels which carry raw goods, such as grain, coal, timber, wool, etc., it is advantageous to have no intermediate decks, for, with only one large hold space, the cargo may be more readily stowed and discharged. In sailing-ships the second tier of beams (usually closely spaced) may or may not be laid as a deck; usually it is not (or is only partially laid, as shown in Plate 101), but should a platform be required at any time, a temporary one may be readily formed; and this arrangement is sometimes adopted in steamers (Plate 10). In passenger vessels and those engaged in the fruit or general coasting trade, one or more intermediate decks become essential; for the 'tween-deck spaces permit of the stowage of delicate cargo, and of separating goods consigned to different ports. If all were piled in one mass in the hold, packages could not be discharged as required, and the undermost might be damaged by excessive pressure.

Art. 122. The function of the beams as ties and struts, and as forming the structural framework of the deck, are specially noticed in Arts. 25 and 37; and it is now intended to consider them in their character as **beams proper or joists.** If they had only to act as such it would be a simple matter, if the maximum load and its disposition were known, to compute the precise **scantlings** compatible with any required margin of strength. The beams of a ship, however, have not this one simple duty, for they must also act as ties and struts, holding the vessel's sides, and, when the deck is plated, as stiffening bars, so that the plating may not buckle or shirk its work under longitudinal stress. Even if their duty as supporting joists were alone considered, it would be a difficult matter to determine, theoretically, the necessary scantlings, because of the impossibility of accurately estimating the weight and distribution of the maximum load which they might be called upon to carry. In the case of a weather deck, for instance, under ordinary circumstances it has little or no weight to support, but it may on occasion carry a deck load; and besides this, it may be subjected to downward pressures from falling seas, the intensity of which it would be hard to predict. Cases have occurred where, through encountering a large tidal wave, the forward part of the upper deck has

collapsed under the enormous pressure and concussive effect of a large volume of water falling upon it. It is evident, therefore, that to enable the upper deck to withstand, without straining or leakiness, all abnormal stresses, the strength of its beams must be largely in excess of what might be sufficient under ordinary conditions.

Lower decks are not exposed to falling seas, and in their case, therefore, it is possible to assume certain conditions of loading, from which, as a basis, the scantlings of the beams, as supporting joists, may be computed.[1] The results, however, would have to be largely modified to provide for the virtual increase in the load caused by the vessel's vertical and rolling movement in heavy weather (Art. 8), and the simultaneous endwise stresses, concussive and statical, due to water striking or pressing on the sides of the hull. As showing the effect of a vessel's movement in increasing the stresses on the beams, it has sometimes been found that the lower deck beams of a sailing-ship (which for many years may have carried cargoes without evidence of weakness), after an exceptionally stormy voyage, have bent downwards between the pillars.

Art. 123. The pillars have, of course, an enormous **effect in increasing the** weight-carrying **capabilities of the beams.** When supported in the centre, one beam practically becomes two, each of which, being of half length, is twice as strong. That is to say, while suffering the same internal stresses of tension and compression, each semi-beam could support twice the load formerly borne by the whole unpillared beam; but, as the weight which (with the same uniformly distributed cargo) each would bear would only be half that borne by the whole, the bending tendency and resulting stress on the material would only be one-quarter of what they were before. The introduction of a central pillar has, therefore, the effect of reducing the stresses on the material of the beam by 75 per cent. Stated generally, the stresses suffered by beams of different lengths, uniformly loaded, varies as the square of the length. In the case, therefore, of a beam supported by two pillars, the stresses suffered by the material of any one-third part would be one-ninth of that experienced by the unpillared beam, and with three pillars, one-sixteenth. By virtue of the beam knees, the ends of the beams are fixed in direction, a circumstance which, with uniform loading, has the effect of increasing their strength by about 50 per cent. of what it would be were the ends free. Further, while the attachment of a pillar to a beam does not hold this part fixed in direction, like a beam knee does, still, when the load is uniformly distributed, the supporting effect on each half of the beam is precisely that of a beam knee (see Fig. 6, Plate 2). In the case of a beam with fixed ends, the greatest stress, when the load is uniformly distributed, occurs at the ends, that at the centre being only half as great; and as, in ships' beams, the bulb or lower edge (being further from the neutral axis than the flange) suffers the greatest stress, the most severely tried part is the bulb or lower edge at the beam knee. In practice this is often observed to be the case, for when a beam bends permanently under an excessive weight of cargo, signs of excessive compression may usually be observed in the material at these places.

Art. 124. Lloyd's rules for beams take into special consideration the increase in strength, or reduction in stress, which follows from efficient pillaring. Formerly the scantlings of the beams were decided practically without reference to the number of pillars; now, if two pillars are fitted

[1] An interesting study of the strength of ships' beams in relation to the pillaring will be found in a paper by Mr. W. D. Archer, *Proceedings of the Institution of Engineers and Shipbuilders in Scotland*, 1894.

instead of one, the beams may be reduced in sectional area by about 20 per cent., and with three pillars instead of one, by about 40 per cent. (in small beams 20 and 40 per cent. become 15 and 30). It should be noticed that a pillar, while greatly assisting a beam as a joist, does not increase its capabilities as a tie or strut to the vessel's side, and, accordingly, when its duties in the latter aspect are of special importance, the large reductions in scantlings just mentioned are not permissible. Thus, in the case of a vessel having only one deck, the beams, besides supporting the deck, must provide unaided all the necessary support to the sides, and in their case, therefore, the introduction of one or two additional pillars, instead of permitting a reduction of 20 or 40 per cent., only permits of about 15 or 25 (in small beams 10 or 20).

The **scantlings of the beams,** as tabulated in **Lloyd's rules,** depend upon their length, the number of pillars, and the character of the deck supported. As shown graphically in Figs. 8 to 13, Plate 3, there are five classes of decks, for each of which there is a special size of beam. The classification in the following is adopted merely for convenience of reference, corresponding numerals being employed in the sketches.

The beams of **class 1** are **the heaviest** (with the exception noticed in the next paragraph); they are required in cargo steamers for all decks excepting the upper one.

Those of **class 2** are **rather lighter** (when both have only one pillar), by about 7 per cent. in sectional area. They are fitted to the upper decks of steamers which have no other deck or tier of beams, and to the upper decks of sailing-ships whether or not there is a second deck. They are lighter than those just noticed because they have no cargo to support, but when placed under a bridge-house wherein coal or cargo may be stowed, they are made of class 1 size. As just noticed, the introduction of one or two additional pillars permits of a reduction in the sectional area of these beams of about 15 or 25 per cent., whereas in others which have not alone the duty of holding the vessel's sides, the corresponding figures are 20 and 40; it follows, therefore, that while with a single row of pillars these beams are about 7 per cent. lighter than those of class 1, with two rows they are practically of the same size, and with three about 16 per cent. heavier.

Those of **class 3** are **still lighter,** being about 15 per cent. smaller in sectional area than those of class 1. They are fitted to the uncovered upper deck (except awning and shelter decks) of all steamers having two or more decks or tiers of beams; also to decks the spaces above which are intended solely for passenger accommodation. Comparing them with the last, it is evident that light scantlings are permissible, for, with another deck or decks, they have not the sole duty of holding the vessel's sides against collapsing or racking stresses.

Those of **class 4** are **again lighter**—by about 30 per cent. They are suitable for awning, shelter, or forecastle decks, and for bridge-houses whose length exceeds one-tenth that of the vessel. It is evident that these beams may be of light scantlings, for the upper 'tween decks they enclose is here really a superstructure on the hull proper, and, being well out of the water, is little exposed to the violence of the waves.

Those of **class 5** are **the lightest,** being about 40 per cent. smaller in sectional area than those of class 1. They are suitable for poop-decks, and for bridge-houses shorter than one-tenth of the vessel's length. It is evident that the beams of a forecastle should be stronger than those of a poop, for when the vessel plunges bows-under in the waves, they are liable to crushing downward pressures and side shocks. When a bridge-house is

so short as one-tenth of the vessel's length it becomes a mere deck house, and, as such, does not require the strength of a long bridge, more particularly as the latter permits of a small freeboard, and is, therefore, more liable to receive shocks from the waves, and to be momentarily covered with solid water.

Sailing-ships are particularly exposed to transverse racking stresses, and, as they have no 'midship bulkheads, their **beams have a special duty** in giving transverse strength and rigidity to the hull. In view of this, therefore, they are made heavier than those of steamers. Thus, while the upper-deck beams in a steamer having two decks may be of the 3rd class, those in a ship must in all cases be of the 2nd. Further, the scantlings of the lower-deck beams in a ship are those of the upper increased in depth by 1 inch, which usually gives a heavier beam than those of the 1st class required in a steamer. As already seen (Art. 35), whereas a steamer may require three tiers of beams, a sailing-ship of the same size need only have two, hence the greater necessity for special strength in the beams of the second deck. Of course, the absence in a ship of a third deck and 'midships bulkheads is compensated for by the fact that the scantlings of the framing, plating, and other parts are heavier than in steamers of the same over-all size, and they do not load so deeply (Art. 46).

In the case of the **shade** and **promenade decks** of passenger vessels, the scantlings of the beams depend on the size of the vessel and whether or not the deck is liable to important stresses; in many cases light angle or tee bars are sufficient.

Art. 125. To support efficiently a wood deck the maximum **spacing of the beams** is two frame spaces, or about 4 feet; if much greater the deck planks would yield too readily between them, to the prejudice of the caulking. In the case of a plated deck they may also be placed on **alternate frames**, but not if the plating is thinner than $\frac{8}{20}$ inch; in such cases they must be on **every frame**, their scantlings being suitably reduced. The reduction given in Lloyd's rules is equal to about 45 per cent. in sectional area, which is nearly proportional to the reduction in the spacing (Figs. 3 and 4, Plate 74). If, with plating so thin as $\frac{7}{20}$ inch, the beams were as far apart as two frame spaces, their stiffening effect would be inadequate; not only would it be difficult to fit the plating with a fair surface, but it would not remain so; it might buckle up or down between the beams by the mere weight of superimposed cargo, or when subjected to but small structural stress. It has already been observed that when a plated surface is wavy or undulating, its efficiency under stress is very poor. When a plated deck is sheathed with wood, the lateral stiffness and protection from local pressure and wear and tear which the planking affords, permits, even with thin plating, of the beams being placed on alternate frames.

When the thickness of unsheathed deck plating is $\frac{8}{20}$ inch or more, its lateral stiffness is such as to permit of the beams being placed on alternate frames; nevertheless, it is evident that its efficiency under stress must be greatly improved by placing these twice as close together, *i.e.* on every frame, and, accordingly, at the sides of hatchways or other large deck openings, where a large degree of efficiency is required, they are so spaced, or the deck plating made at least $\frac{1}{2}$ inch thick in the case of steel, and $\frac{5}{8}$ inch in the case of iron. At these places the cross sectional area of the deck is reduced by the openings, so that superior strength and stiffness are very desirable; and this is more particularly the case in way of the machinery openings, for, being amidships, it is here that the deck and

other parts of the structure are most severely tried by longitudinal stresses.

Art. 126. The **scantlings of the beams** of any particular deck are regulated by the length of the 'midship one; but as they shorten **towards the bow and stern,** so do they become stronger and more capable in every way, and, accordingly, a reduction becomes permissible either in their scantlings or pillaring. It has already been noticed that for each beam of any particular length there are three sizes—one appropriate to a single-pillar support; another, rather smaller, to a two-pillar support; and another, still smaller, to a three-pillar support. In the diagram, Fig. 14, Plate 3, three beams are shown, supported respectively by one, two, and three pillars, their comparative strengths being represented by their thicknesses. Now, in the case of No. 1, it is evident that when its length is reduced to two-thirds, its appropriate size, with still a central pillar, is that of No. 2, and when reduced to half, to that of No. 3. In the case of No. 2 beam, when its length is reduced to two-thirds, an appropriate reduction in its superabundant strength may be secured at once by merely suppressing one of the two pillars, and when reduced to half length, by making it of the three-pillar size. Again, in the case of No. 3 beam, when reduced to three-quarters of its full length, the suppression of one of the pillars at once provides the desired reduction in strength, and when reduced to half length, the suppression of another gives the same result. The foregoing represents the requirements set forth in Lloyd's Rules.

If the beams were regarded theoretically, as supporting joists only, and if all were equally pillared, then, of course, while maintaining the same strength, the reduction in scantlings (or pillaring) might go on continuously, so that the terminal beams at the bow and stern, being quite short, might be perfectly slender. There are many circumstances, however, which render such treatment inadmissible. The end beams, though losing their importance as supporting joists, are subject even more than the 'midship ones to exceptional stresses. When the vessel plunges bows-under in the waves the concussive blows on the sides of the hull are almost entirely met by their strut-like resistance, and, evidently, to resist such shattering influences, massiveness in the beams and hull generally is essential. It might appear that greater uniformity in strength would be attained if, instead of dividing the beams into two or three groups of diminished length and correspondingly diminished scantlings, they were divided into twice or three times as many. This might be desirable if the difference between the maximum and minimum scantlings in each group were considerable, and if the contour of the deck were so tapered as to give numerous beams of widely different lengths; but as this is not so, there would be no appreciable benefit. In practice, to introduce a large variety of beams of slightly different sizes for the sake of greater theoretical perfection, would cause trouble and difficulty; and delays would occur in securing delivery from the steel works of small batches of bars of different scantlings.

Art. 127. The **hatch-end beams,** *i.e.* the beams at the ends of hatchways, have a special duty, for they support, through the medium of the fore-and-aft coamings, the inner ends of all the severed beams—*half beams*—lying between them. They have, therefore, a large area of deck to support, and, in the absence of through-beams between them, a greater duty in holding the vessel's sides against racking and panting stresses. This is often evidenced in sailing ships, for signs of straining, though nowhere else observable, may commonly be seen in the riveting of the knees of these particular beams. In practice, therefore, in decks having beams

of the light scantlings appropriate to a one-frame spacing, those at the ends of hatchways (between six and twelve frame spaces in length) are made of the large size appropriate to a two-frame spacing. Further, while ordinary upper deck beams may be of the small No. 3 class, those at the hatch ends must be of the larger No. 1 class. In the case, however, of light shelter, awning, or bridge decks whose beams are of the No. 4 class, those at the hatch ends may be of the No. 3 class. Owing to the incidence of the coaming plates, the hatch-end beams must be modified in section or reversed, so as to present a flush surface within the hatchway. If elsewhere of tee-bulb section they are here formed of a bulb plate with a single large angle of proportionate size; or they may be of channel or bulb-angle section (Figs. 5 to 8, Plate 58). When the deck is of wood, a bulb plate and single angle is convenient in that, by making the horizontal flange of the latter 5 or 6 inches wide, it affords a wide ledge for the ends of the planks (Fig. 5); if narrow, the bolts would fall too near the plank ends, in which case a cross plate would have to be fitted (Fig. 6).

The **half-beams** at the sides of the hatchways, being little more than one-third the length of the 'midship beam, need not be of heavier scantlings than that appropriate to beams having two rows of pillars, provided, of course, a complete row of pillars (two frames apart) or its equivalent, is fitted on either side. As a rule, however, they are made of the larger "one-row" size, which permits of the pillars being fitted on alternate ones (4 frames apart, Art. 142).

Art. 128. There is a sixth class of beam not yet noticed, namely, the **strong beams, or hold beams of extra strength**, which are placed at wide intervals in the holds or machinery space. The scantlings tabulated in Lloyd's rules for these beams gives them a sectional area about twice that of the heaviest deck beam, and as they serve merely as struts and ties, their scantlings do not vary with the pillaring. Several different formations commonly adopted are shown at H to S, Fig. 1, Plate 12. Those shown at H and O are particularly specified in Lloyd's rules for the holds, that shown at R being specified for the machinery space. The section shown at I is commonly adopted in place of that shown at H, because a bulb bar is more readily procured from the steel works than a plain flat bar. In these isolated hold beams lateral rigidity is even more important than beam-like strength, for while they are supported vertically by the pillars, they receive no lateral support at all; other beams are, of course, tied together by deck plating, planking, or tie plates. For this reason the semi-box formation shown at N to R and Fig. 6, Plate 9, is evidently the most efficient. Those of bulb-tee section (L), if adopted, must have a wide top flange, and as solid bulb-tee bars cannot be rolled with a flange wider than about 7 inches, the addition of a covering plate becomes necessary. Formerly the section shown at L was the one commonly adopted for hold beams. As hold beams are particularly exposed to rough treatment in working cargo, a projecting flange is apt to be battered and broken, hence it should evidently be thick and strong. The semi-box beams shown at N to P are advantageous in that, as they have no salient edges, they are well able to resist wear and tear; compared, however, with the beam shown at H, a semi-box one has the disadvantage of offering more obstruction to cargo (see Figs. 6 and 8, Plate 9). In some cases, where the frame-spacing is so great as 30 inches, one of the beams forming a semi-box is kneed horizontally near the vessel's side, so as to reduce the breadth of the beam and thus cause less obstruction to cargo (Fig. 10, Plate 9). As already noticed, all such isolated beams are provided with an extensive connection to the vessel's side, by means of gussets to the stringer plates (Plate 9).

The **beams** to which the **heads of web frames** connect should have strength in some degree proportionate to that of the web frames themselves. In cases, therefore, where beams of light scantlings are fitted on every frame (below a thin steel deck), those in way of web frames must be of the large size appropriate to a two-frame spacing (Fig. 11, Plate 4). If the deck is not plated, the beams which take the heads of the web frames must be of strong hold-beam type (Fig. 10, Plate 4, and Fig. 3, Plate 8). Further, when the head of a web frame connects to a half beam at the sides of a hatchway, a specially large bracket knee is required.

Art. 129. Although, in the **machinery space**, numerous beams must be severed or suppressed, it is always practicable, without seriously interfering with the machinery arrangement, to retain one or more at each deck level, making them of the massive **strong-beam** type just noticed (see Plates 27, 108, 109, and 110). They cannot be placed over the engine, for here a clear space is required for lifting the cylinder covers; but between the engine and boilers there is usually room for one at the level of the lowest deck, and for one or two at the decks above, where quite clear of the tops of the boilers; also, there may be space at the forward end of the boiler room, in the stokehold. Where practicable they should fall upon web frames, and be connected thereto by large brackets, both vertical and horizontal (Fig. 4, Plate 8). Sometimes, in order that they may fall upon web frames, they are slightly bent or kneed, horizontally, and in some cases, to clear the top of a large central boiler, they are arched upwards between the casing sides. Where several beams are fitted consecutively at the second or upper deck, they are plated over so as to form a platform for a donkey boiler or galley (Plate 108). They are supported to a certain extent by the casing sides and coal-bunker bulkheads through which they pass, but these may be too slender to hold them rigidly against vibrating and other stresses. If not pillared at the centre, they should be, at each side, close to the casing or bunker bulkheads; unless the latter are stiffened in the thorough manner described in Art. 224.

Art. 130. Deck beams may be of *angle*, *bulb-angle*, *solid bulb-tee*, *built bulb-tee*, or *channel* section, for all of which equivalent scantlings are tabulated in Lloyd's rules (Fig. 1, Plate 12). When heavily loaded, a beam having a single top flange, such as a bulb angle, tends to cant or strain sideways. When well riveted to a plated deck the plating forms a wide top flange, so that canting cannot well occur without distortion of the beam itself. With a wood deck, the bolt fastenings have not the rigid clamping effect of rivets; passing through soft wood and through holes in the beams of larger diameter than their own, they may not hold the beams sufficiently rigidly to prevent straining; under severe stress the latter may pull away from the planks and twist sideways. A tee-bulb section is, therefore, specially suitable for wood decks, for the double top flange provides a wide base for the bolt attachment, and, owing to the symmetry of its section, it is stable under stress; further, the wide top flange gives a better support for the butts of the planks (Fig. 22, Plate 56). In view of the above, Lloyd's rules state that in vessels over 34 feet in breadth, beams of bulb angle section, when placed on alternate frames, must be plated over.

In **cargo vessels, beams** with a single top flange (angle, bulb-angle, or channel bar) are usually preferred, and if the thickness of the deck permits, they are placed on alternate frames; for, of course, with half the number of beams to make, fit, and rivet, the cost of construction is reduced, In many cases the thickness of the deck plating is increased to permit of a wide spacing in the beams. A single top flange is advantageous, in that less riveting is required to secure good contact with the deck plating, and

it is an easier section to work. When on alternate frames, single-flange beams are specially massive, and to secure, therefore, with a single row of rivets in the top flange, a sufficiently rigid connection to the plating, Lloyd's rules require the usual rivet pitch of 7 dias. to be reduced to 5. In **passenger vessels** the beams of the cabin decks are usually placed on alternate frames (except those having an extra wide frame-spacing), for a wide spacing suits the cabin arrangements better, and is permissible because the decks of such vessels are generally of wood, or are wood sheathed. And bulb-tee bars are usually employed, because their neat, symmetrical appearance is appropriate to the decorative work of the cabins. Z bars are not often used for beams, for they are inferior to channels and awkward to work. Simple angle bars are employed for the plated decks of small vessels, and for light awning decks, bridge decks, etc. Tee bars are used only for light decks, such as shade and promenade decks of passenger vessels, for here, though not very efficient as beams, they may be amply strong, and the wide top flange is convenient for the fastenings and joints of the planks.

In the earlier iron vessels the beams were all of **built bulb-tee** section, for, although bars of solid section, or "**butterly bulb**," as it is sometimes termed, were obtainable, they were costly and could not be rolled in long lengths. Now, with steel, they may be rolled as readily as any other bar, and, accordingly, built bulb-tee beams are not often employed. They are still used, however, for they are advantageous in that, by employing large angle bars, the top flange may be made of any breadth; with rolled bars it is limited to about 7 inches; also, one angle may be discontinued where required, in way of hatchways, casings, etc., and in small shipyards they are easy to manipulate. In the early days of iron shipbuilding, Lloyd's rules did not present a complete tabulated list of scantlings, those of the beams as of other parts being regulated by simple, proportionate rules. The bulb plate was made $\frac{1}{4}$ inch deep for each foot of its length, and $\frac{1}{16}$ inch thick for each inch of its depth. The combined breadths of the two flanges of each angle bar was three-quarters the depth of the bulb plate, and their thickness $\frac{1}{16}$ inch for each inch of such combined breadth.[1] The proportions and form assumed in Lloyd's scantlings for bulb-tee, bulb-plate, and bulb-angle beam sections, and which are generally adhered to in the rolling mills, are shown in Figs. 1, 2, and 3, Plate 74.

When **beams** support a **plated deck** they receive therefrom much additional strength and perfect lateral stiffness; with a **wood deck**, though they receive little or no additional beam-like strength, they acquire ample lateral stiffness. In the case of a lower tier of closely spaced beams, on which no deck is laid, the only lateral support received by the beams is that due to the fore-and-aft tie plates, and, for this reason, such beams are practically always of bulb-tee section, for, having a double top flange, they have greater lateral strength and stiffness than either a bulb-angle or channel beam. In the loading of compressible material, such as cotton or wool, the beams and pillars are often bent and distorted by the shores and jacks used in the stowing operations, hence a further necessity for ample stiffness and strength, both laterally and vertically.

Art. 131. The **beams** of the different decks are **placed over each other on the same frames**, so that the pillars in the 'tween decks and hold may form contiguous ties. And those which have a single top flange

[1] This rule for the thickness of angle and bulb bars is a convenient one; with variations of one or two twentieths in the thickness, nearly all bars used in shipbuilding conform to it; of course, with steel, sixteenths become twentieths.

are disposed with the flange facing the opposite way to the reverse frame (inner flange, or bulb), otherwise the flange must be cut back to clear it (Fig. 15, Plate 89). In tee-section beams, one flange must be cut back (see Figs. 2 to 4, Plate 12). For the purpose of draining water to the ships' side, all decks are *cambered*, *i.e.* arched athwartship, in the arc of a large circle. When there are several decks, all have usually the same camber, *i.e.* they are struck with the same radius; but in passenger vessels the lower ones are often flatter, for here camber becomes unimportant, and, of course, a level floor in the cabins is very desirable. In channel steamers and yachts the cabin deck is usually quite flat. Beams on which there is no deck laid are often quite straight. It should be observed that a camber increases but little the strength of a tier of beams; the principle of the arch hardly applies here, because not only is the arch too flat, but it has no independent abutment, for the sides of the hull are tied together by the arch itself.

Art. 132. As noticed in Art. 33, the security of the **beam knees** and their efficiency in holding the ship's side depend greatly on their depth. **Lloyd's Rules** in this respect are as follows: The depth of each knee is regulated by that of the beam itself and by the number of supporting pillars. As already noticed, three sizes are given for each beam; one, the largest, for beams having one pillar; another, smaller, for those having two; and another, still smaller, for those having three. Now, the introduction of pillars, while greatly assisting a beam as a joist, does not help it in holding the vessel's sides against racking and panting stresses, and consequently it is evident that, although the depth or strength of the beam itself may be largely reduced on account of the pillars, that of the knees may not. Lloyd's rules take account of this; for while the knees of a single-pillared beam may be $2\frac{1}{2}$ times that of the beam, those of a two-pillared one must be $2\frac{3}{4}$ times, and those of a three-pillared one 3 times the depth of the beam. In the case, for instance, of a single-pillared beam 9 inches deep, the addition of a second pillar permits of its depth being reduced to 8 inches, and that of a third to 7 inches. By the foregoing rule, therefore, the depth of the knees in the first would be 9 by $2\frac{1}{2}$, or $22\frac{1}{2}$ inches; in the second 8 by $2\frac{3}{4}$, or 22 inches, and in the third 7 by 3, or 21 inches. There is thus little difference in the depths of the knees. As beam bars may vary in depth (according to their precise section and scantlings), the depth and thickness of the knee are based on the T-bulb and angle-bulb beams tabulated in the rules (for a two-frame and one-frame spacing respectively). Where the beams have a special duty in holding the sides, the minimum depth of the knees is three times that of the beams, irrespective of the pillaring. This applies in the following cases: All the beams in sailing ships; the upper-deck beams of steamers which have only one deck; the upper-deck beams in way of hatchways in vessels having two decks, *if* at these places the half-beams of the deck below are omitted (Figs. 1 and 6, Plate 10); the beams of the lowest deck in vessels in which a lower deck is suppressed in favour of web or deep frames; the beams which support the crown or top plating of a deep tank (Art. 199); and beams whose length is 44 feet and above, and which are supported only by one row of pillars.

To ensure that the beam knees shall not be too narrow at the throat, Lloyd's rules require their breadth at this part to be not less than six-tenths of their depth (Fig. 2, Plate 12). They also specify the number and size of the rivets required in knees of different depths; these vary from four $\frac{3}{4}$-inch rivets in a 17-inch knee to nine $\frac{7}{8}$-inch rivets in a 40-inch one. In practice, however, the number of rivets must often be increased in order thoroughly to bind the two parts together.

Art. 133. There are two **types of beam knees,** the *welded* and the

plate (Fig. 2, etc., Plate 12, and Fig. 6, Plate 81). Of the former there are two kinds, the *turned* and the *slabbed*. The **turned knee** (Figs. 2 to 5, Plate 12) is the best of all, but it is also the most costly. In the early iron vessels the beam knees were always turned, but now, except in sailing ships, turned knees are comparatively rare. As the beam knees of sailing ships are particularly liable to be strained by the severe racking stresses to which these vessels are exposed, Lloyd's rules require those which are welded to be of this kind. The procedure of forming a turned knee is shown in Figs. 11 and 12. With a built beam, the entire bulb bar is turned down at the end, and a triangular piece, shown by the shaded area, is then welded in to form a square upper corner (Fig. 12). With a bulb-tee or channel bar the bar is split, and only the lower part turned down, a triangular piece being welded between the two parts (Fig. 11). Sometimes in this type of knee a small triangular hole is left (Fig. 3). This is commonly done in warships; it is advantageous in that it tends to reduce weight, there is less welding work, and the holes may form convenient leads for electric cables, etc., or may be useful for ventilating purposes.

In most cases, when welded knees are adopted, they are of **slabbed type**; the method of forming them is shown (Figs. 6 and 7, Plate 12). The lower edge should curve gradually into the beam; but, of course, if it is sufficiently wide at the throat, this becomes less important. A turned knee is superior to a slabbed one, because, as it is wider at the throat, there is no sharp corner to cause localization of stress, and there is no chance of weakness through defective welding, the weld being at a part not subject to stress. In a slabbed knee, the "slab," "knee piece," or "beam arm" (B, Figs. 6 and 7), as it is variously termed, may be a cutting from a plate or from a wide bulb bar. The former is advantageous in that it is an easy matter to cut the plate with a considerable curvature, and thus avoid a sharp corner at the throat; if cut from a bulb bar, the meeting of the two edges is necessarily somewhat acute. It is, of course, desirable, in the case of a bulb beam, that the bulb should be continued down the edge of the knee, so as to avoid any discontinuity in the strength; but when it is not, as is common, the necessary strength may be readily secured by simply increasing the width at the throat. It is common to use iron for the slabs in place of steel, because most workmen find it easier to weld with this material; but, in this case, the slabs should be made rather thicker, to compensate for their inferior strength. The welding of beam knees is sometimes carelessly done, the junction of the two parts being often clearly visible as a crevice on one side or the other; and sometimes the material is rendered brittle by overheating, so much so that a blow from a sledge-hammer may be sufficient to break the knee off, in the line of the weld.

Art. 134. Plate knees are formed by riveting a bracket plate to the beam (Plate 105). They are very largely adopted, for, although heavy and clumsy compared with a welded knee, they are easily made; being wider at the throat, they are stronger, and, in the absence of welding, perfectly reliable. They are not so suitable for bulb-tee beams, because the bulb interferes and must be removed on one side (Fig. 12, Plate 81) or bent out of the way (A, Fig. 12). The twisting of the bulb, however, may be readily done in a hydraulic press. The horizontal dimension of the bracket plate is the same as the vertical one, and the thickness is that of the beam, of which it may be regarded as an extension. In small knees the inner edge is usually straight, but in large it is generally cut with a slight curve, so as to save weight and lessen the interference with cargo stowage. The plates are usually machine riveted to the beams

before erection. With this type of knee and built frames, there are one or two four-ply rivets in the end of the beam (Fig. 15, Plate 6, and Plate 105). In the case of the upper-deck beams these may be avoided by terminating the reverse frame at the lower edge of the beam. If, in the case of deep frames, the reverse bar is not fitted in the bosom of the frame, there is an awkward crevice at each knee (Fig. 15, Plate 6). If the frame is very deep, the reverse bar may project sufficiently—about four inches—to take the knee, in which case the pitch of the frame and reverse-bar rivets should be reduced at this part. In some cases, while the knee plate connects only to the reverse bar, the beam is run in so as to take additional rivets through the frame angle (Fig. 16).

In the case of the poop decks of sailing ships, when the **gunwale** is **rounded** the frame terminates at the lower part of the curve, so that only the beam need be bent (Fig. 8, Plate 12). There are here no beam knees, the beams being simply extended down to scarph with the frames. In these light decks there is little need for special rigidity at the gunwale; the beams are slender, and, owing to the rounded gunwale, there is no sharp corner to cause localization of stress. In the case of **turtle-back forecastles and poops**, although the deck is curved downwards at the gunwale, it may, nevertheless, meet the side more or less abruptly (Figs. 9 and 10). So long as the angle of incidence is fairly obtuse, the union of beam and frame may be made as above, without a knee, but when it approaches the square, a more or less perfectly formed knee may be necessary to give the effect of a stiffening fillet in the otherwise sharp corner (see Fig. 9). The special knee connection required for strong beams of I section, and for those which fall on web frames, is illustrated in Fig. 4, Plate 7, and Figs. 3 and 4, Plate 8.

CHAPTER XII.

Art. 135. The **pillars** or **stanchions** not only assist the beams as joists, but relieve their end connections. In an unpillared 'tween-deck beam, the whole weight of 'tween-deck cargo falls upon the beam knee rivets, being transmitted thence, down the ship's side and round the bilge, to the bottom, where the counterbalancing upward pressure is situated. The weight of 'tween-deck cargo thus tends to depress the bilge, as shown in exaggerated form in Fig. 3, Plate 2, and it is at once evident that the introduction of a centre pillar, by taking half the load (assuming a homogeneous cargo), must reduce, by half, the pressure on the beam-knee rivets, the depressing effect on the bilge, and the bending tendency on the floors. Besides acting as struts, the pillars tie the decks together and to the vessel's bottom, so that they may strain neither upwards nor downwards. In a large ship, the 'midship section forms a slender rectangular figure, which may display considerable flexibility; in heavy weather, the beams may yield and bend under the panting and racking forces acting on the sides. In a steamer, the oscillating masses of the engine tend to set up a corresponding pulsating effect in all flexible parts of the hull, and, more particularly, to cause drum-like vibration of the decks; and it is evident that the pillars, by rigidly holding these at fixed distance from one another, and from the bottom, must have a commanding effect in checking such elastic movement. Vertical pillars can give little or no resistance to transverse racking stresses, to do this they must be disposed diagonally, and in flying superstructures of shade-deck type, which are supported merely by an extension of the rail stanchions, they are sometimes so disposed, in pairs, about twenty feet apart.

Art. 136. When subjected to an overpowering load, **a pillar gives way by side bending,** and if its length is great compared with its diameter, its failure may occur under a comparatively small load, quite out of proportion to what its sectional area alone might indicate. Further, when it begins to bend, its failure becomes complete forthwith—assuming the maintenance of the load. In the case of a pillar which is so short as to be a mere cylinder, it is evident that, however severe the load, it would not bend; it would stand erect, and, if of soft, ductile material, fail ultimately by staving up and bulging; or if of hard material, by shearing across diagonally or by general disintegration. The supporting power is here measured simply by the sectional area of the pillar, being equal to about twenty tons per square inch of same. The strength of a long pillar has been found by some experimenters to vary as the 3·6 power of its diameter, and inversely as the square of its length. Much depends, however, on the way its ends are secured; the strength when both ends are fixedly held, as by large palms, may be two or three times greater than when both are pivoted, as by ball-and-socket joints.[1] The reason for this greater strength

[1] The results of a series of experiments on the strength of pillars will be found in *Engineering* for the 6th June, 1902, in a paper read by Mr. J. M. Moncrieff.

will be evident from Fig. 33, Plate 13, for, as there shown, failure of a pillar having fixed ends involves three short curvatures, whereas that of one with free ends involves only one long one. As just seen, a very short pillar does not fail by side bending, but stands up to its work until its material actually crushes. When fixed at both ends, pillars of considerable length may display this continued erect endurance, and, in practice, the capabilities of those up to about twenty-five diameters in length is commonly estimated on this assumption, namely, that their strength is proportionate to their sectional area, and although not quite correct, the large factor of safety generally allowed is ample to cover any discrepancy.

Art. 137. In deciding the **diameters of ships' pillars,** account must be taken of the fact that the cargo in the 'tween decks is, in effect, a live load, for, as the vessel lifts to the waves, pitches, and rolls from side to side, it (the cargo) is forced to move with it, so that its weight or downward thrust on the beams and pillars may be increased, virtually, by a very large amount. Further, their diameters cannot be decided merely by their theoretical capabilities as supporting columns, for one which might be amply strong as regards the maximum load it would ever be called upon to sustain, might be too slender to withstand the accidental side pressures to which in active service it is liable. For instance, a lower 'tween-deck pillar 7 feet long, by 3 inches diameter, would have an ultimate supporting power of 80 or 100 tons, and as the weight of homogeneous cargo, filling the upper 'tween decks, that would fall upon it, would rarely, if ever, exceed 12 tons, the factor of safety, regarding it as a strut, is evidently large. But even stouter pillars than this are not infrequently bent or broken, it may be by blows received during loading and discharging operations, or by side pressure from cargo, bearing upon them as the vessel rolls or perhaps through shifting of the cargo; and, of course, when once bent, the efficiency of a pillar is lost. Another matter which calls for massiveness and stiffness is the comparative meagreness of the end connections. As a rule, there is only a pair of rivets in either end; so long as the pillar remains straight these are sufficient, but if it should deflect through side pressures or blows, an enormous stress at once falls upon the rivets (on the principle of the toggle joint) tending to shear or loosen them; in practice they often give way from this cause. It follows, therefore, that by giving massiveness to the pillars, so that they cannot be readily bent, their end connections are rendered more secure.

Art. 138. Lloyd's rules for pillars are as follows: In the first place, the diameter of each one, wherever situated, depends upon its length; thus, while an 8-foot pillar may be $2\frac{3}{4}$ inches diameter, a 28-foot one, supporting the same beam, would be 5 inches diameter. The different lengths tabulated in the rules are given in steps of 2 feet, the diameters of the pillars varying by $\frac{1}{8}$ inch, for small ones, and $\frac{1}{4}$ inch for large. In the case of the long pillars tabulated in Lloyd's rules, their strength, when regarded merely as struts, is greater than that of the small, but as their great length renders them liable to excessive side pressure from cargo, an ample margin of strength is evidently very necessary.

Their diameter also depends on what deck they support. Those in the upper 'tween decks are the smallest, for they only support the upper deck; those under the second deck are larger, and those below still larger, for they support the cargo stowed in the 'tween decks. In cases where the upper 'tween-deck space is intended solely for passenger accommodation, the pillars below, having no 'tween-deck cargo to support, may all be rather smaller, Lloyd's rules permit of a reduction in their diameter of $\frac{1}{4}$ inch; and if a

second 'tween-deck space is also devoted to passenger accommodation, a reduction of $\frac{1}{2}$ inch is allowed.

Their diameter also depends on the length of the 'midship beam. Thus, while in a small boat of 15 feet beam, $2\frac{1}{4}$ inch pillars suffice, in a large one of 40-feet beam, a pillar of the same length must be $2\frac{3}{4}$ inches diameter.

In vessels less than 43 feet beam, **one pillar** at the centre of each is sufficient; in those between 43 and 55 feet, **two** are required (by Lloyd's rules), dividing the beam into three equal parts, and in those over 55 feet beam, **three**, dividing it into four.[1] It is evident that as a beam becomes longer and longer, there arrives a time when a mere increase in the diameter of a single centre pillar would not give the necessary supporting effect. Further, as vessels increase in size, the importance of the upper deck as the top flange of the hull (regarded as a box girder) becomes greater and greater, and to fit it for its important duty it must be well held in a vertical direction, and not merely at the centre line. The introduction of one or two additional rows of pillars does not permit of any substantial reduction in their diameters, and, consequently, it at once greatly increases the support given to the beams. Thus, the one, two, and three pillars required by Lloyd's rules for a 39, 49, and 59-foot beam, afford respectively about one square inch of sectional area for each $6\frac{1}{2}$, 4, and 3 feet of beam. This apparent discrepancy is due to the necessity of maintaining ample strength in the side pillars, to enable them to withstand the large accentuation in the load caused by the vessel's rolling movement. As the hull rolls to port, the cargo at the starboard side of the 'tween decks is forced, by the beams and pillars on which it rests, to move quickly upwards against gravity; the side pillars have, therefore, not only to support the mere weight of the cargo over them, but, when thrusting it upwards, must overcome its inertia. The duty of the centre pillars is not much increased from this cause, and in theory, therefore, they might be smaller than those at the sides, but here, again, the necessity for lateral stiffness prohibits any substantial reduction. As already noticed, in the case of beams which, by their length, only require one row of pillars, the addition of one or two more permits of a reduction in the scantlings of the beams. As a rule, however, shipowners prefer as few pillars as practicable, for they greatly interfere with the stowage and working of cargo; and in the majority of cases, therefore, where two side rows are required by Lloyd's rules, only one is fitted, the diameters of the pillars and scantlings of the beams being suitably increased.

In vessels having **one row of pillars**, it is continued from stem to stern; every beam has thus a pillar, the shorter ones towards the ends being reduced in scantlings as described in Art. 126. In those having **two rows** of pillars, one is discontinued when the length of the beams becomes less than $\frac{2}{3}$ of the 'midship one, the other row being continued centrally to the ends. In those having **three rows**, one is discontinued when the length of the beams becomes $\frac{3}{4}$ of the 'midship one, and another when it becomes $\frac{1}{2}$ the length, the remaining row being continued to the ends. The pillars in the different 'tween decks and holds are placed over one another, so as to form continuous vertical ties from the upper deck to the floors.

Art. 139. When beams are placed on every frame, the pillars, being, as before, two frame spaces apart, give direct support only to alternate ones. To distribute, therefore, their supporting effect to all, a **fore-and-aft**

[1] Pillars which are fitted between the centre and side are often referred to as "*quarter pillars.*"

stringer is fitted **under the beams**, in line with each row of pillars (Fig. 20, Plate 12). Without this, the intermediate beams would derive no benefit from the pillars; they would be free to strain up or down, for, of course, the thin, flexible deck plating—the only uniting medium—has little holding effect. The stringers may be of double angles, the size of the reverse frames, or of tee or channel bars of equivalent strength (A, B, C and D, Fig. 17). They are connected to each beam by a lug, but with channel beams the lower flange provides the required attachment. They must be severed, of course, at hatchways and bulkheads, and their ends should be properly connected. The pillars may be riveted either to the stringer or to the beams alongside (F, Fig. 17). When the stringer is securely connected to each beam, the result, in holding the deck, is much the same either way. The latter is sometimes advantageous in that it permits of a larger pillar head, and, therefore, of a better union; when riveted to the comparatively slender and shallow flange of the stringer, there may be insufficient space for a good pillar head; in such cases, the connection sometimes gives way, the pillar head fracturing, or tearing away the flange of the stringer. In the case of the centre-line stringer, a channel section is advantageous, for, by fitting the pillars alternately to the different flanges, they are disposed in the zigzag fashion suitable for shifting boards (see D, Fig. 17). The same result may be accomplished as shown at C, Fig. 17. The stringer should be riveted to the lugs on the beams before the deck is plated, so that the rivet points may be conveniently clinched from above.

The pillar-head stringers are very useful parts; they not only serve their primary purpose of distributing the support of the pillars, but, by acting the part of a keelson, give general stiffness to the deck. In large vessels, or those of disproportionate length, their capabilities in the latter aspect are particularly studied. They are here adopted regardless of the beam spacing, and are worked intercostally, so that, forming deep girders, they not only give superior support to the deck as a whole, but, by stiffening the thin plating between the beams, greatly increase its efficiency under longitudinal stress. Some different methods of constructing intercostal stringers are shown at E to J, Fig. 17, Plate 12.

Art. 140. If the above intercostal stringers were made sufficiently deep and strong, they would become girders so independently capable as to require little or no support between the bulkheads. In practice this principle is now often followed; in vessels where **pillars** would seriously interfere with cargo, they are greatly **reduced in number**, increased in size, and associated with a **stringer of extra massiveness**, securely connected by large bracket plates to the bulkhead at either end of the hold, in the manner indicated in Fig. 23, Plate 12, Figs. 37 and 41, Plate 13, and Plate 24. It should be observed that where it is necessary to give intermediate support to such a girder, say by one pillar at mid-length, the great strength of the girder itself, sufficient, it may be, to withstand alone almost the entire load, does not permit of a corresponding reduction in the capabilities of the pillar. The duty of the latter cannot be of a supplementary character, for it must take one-half the entire load; if unfit for this it will bend, whereupon the girder, being permitted to deflect, will take practically the whole load, transferring it to the support at either end. In a number of large two-deck vessels recently constructed,[1] only two pillars are fitted in each hold and 'tween deck, one on either side. They are of tubular section; those in the hold are 21 inches diameter, and those in the 'tween deck 12 inches, the former being of $\frac{7}{8}$ inch plating, and the latter of $\frac{5}{8}$ inch. They are placed close to

[1] A description of these vessels will be found in a paper by Mr. Henry B. Wortley, *Trans. Institution of Naval Architects*, 1900.

the hatch coamings, and a powerful fore-and-aft deck girder, of open box type, is fitted over each one, extending from bulkhead to bulkhead. The hatch coamings form part of these girders, those of the upper deck being extended beyond the hatch ends, to the bulkhead at either end of the hold. The bulkheads are strengthened under the end of each girder by a deep web stiffener; and the downward thrust of the hold pillars on the tank top is distributed by a special foundation, having a pair of fore-and-aft bearer plates 12 feet long. In small coasting vessels, **all pillars** are sometimes **suppressed**, the deck being made self supporting, by fitting, in conjunction with web frames, deep plate-girder beams (placed at the ends of the hatchways), and fore-and-aft girders to distribute the supporting effect of the latter to the light intermediate beams.

The **built pillars of extra strength** just mentioned are often formed of two channel bars riveted back to back, with or without wide covering plates on their flanges (Figs. 38 and 39, Plate 13); in other cases, they may be formed as shown in Figs. 37, 40, 41, 42, Plate 13. They are superior to solid, round pillars because of their great lateral stiffness, and of the strong and rigid end connection which may be secured by means of bracket plates. It is important in such pillars that their cross-sectional area should be symmetrical, so that they may be no more liable to bend one way than another; and, for the same reason, that the bracket plates at the head and heel should hold them rigidly in all directions. In some cases, where only fore-and-aft brackets have been fitted, the pillars have failed by bending athwartship, assuming the single curvature of a pivoted pillar (see Fig. 33, Plate 13). In the tanks of oil steamers (and sometimes in deep ballast tanks) the pillars are usually of built section, having large bracket ends (Figs. 2 and 5, Plate 24, and Figs. 10 and 11, Plate 26); in the earlier vessels it was found that ordinary pillars, with their meagre end connections were incapable of withstanding the severe local stresses to which this class of vessel is exposed.

Art. 141. Although **pillars** are most useful structurally, they are often **a great hindrance** to the working of cargo. They cut up and obstruct the holds and 'tween decks, so that packages cannot be disposed in the manner best suited for completely filling them, and they hinder the stowing and discharging operations. In one respect they are useful, however, for they prevent shifting of the cargo, and check the tendency to strain or work at sea, with its chafing and damaging effect on the packages; and the more fully to secure this result the cargo is "choked off," by inserting dunnage wood or wedges between it and the pillars. The disposition of the pillars may be varied with a view to lessening the interference with cargo. This is shown in Fig. 13 to 16, Plate 12. In Figs. 13 and 14 the 'tween-deck or hold space is practically partitioned off, by the two rows of closely spaced pillars, into three fore-and-aft sections, which is, of course, a very objectionable arrangement in vessels other than those engaged exclusively in carrying grain in bulk. The other two arrangements avoid this to some extent; but, owing to the double distance between the pillars of each side row, it involves the fitting of strong fore-and-aft intercostal girders under the deck. As the pillars at the sides of the hatchways are particularly in the way when working cargo, they are usually made portable. In the others, portability is also often desirable, but as it is quite possible that pillars when temporarily removed may not be properly replaced, the classification Societies do not sanction such mode of fixture.

Art. 142. When there is only a centre row of **pillars**, those which must be omitted **in way of the hatchways** are shifted out to either side, so as to maintain the same general supporting effect. With hatchways

so long as 26 feet, Lloyd's rules require each hatch-end beam to have three pillars. As already seen, the duty of these beams is augmented by the absence between them of numerous through beams. When there are two rows of pillars (with beams of correspondingly light scantlings) the hatchways do not interfere with them; but as the ordinary two-frame spacing would be a source of inconvenience in working cargo, Lloyd's rules permit of alternate pillars being omitted at this part, provided the diameter of those left is made ½ inch larger, and an intercostal stringer is fitted on either side to distribute the supporting effect to the deck (Fig. 21, Plate 58); or instead of an intercostal stringer the lower edge of the fore-and-aft coamings may be flanged or provided with a large angle bar, and thus form itself an efficient fore-and-aft girder (Figs. 19 and 20, Plate 58). In most cases, however, it is preferred to fit the beams of the heavier scantling appropriate to one row of pillars, which permits of alternate pillars being omitted at the sides of the hatchways, without other special arrangements. An arrangement is shown in Fig. 10, Plate 58, in which all pillars are omitted at the sides of the hatchway; the necessary strength being secured by introducing very powerful hatch-end beams, and fitting a stout channel bar on the lower edge of the hatch coaming, with a gusset connection to each hatch-end beam; the only pillar is a specially strong one at the centre of each hatch-end beam. In the machinery space many of the pillars must be suppressed, in which case the bunker bulkheads and casings are made extra strong, and the coamings reinforced by fore-and-aft angle bars as described Art. 157, and shown in Plate 27.

As already seen, **pillars at the sides of hatchways**, being greatly in the way, are usually **made portable**; in the case, however, of small single-deck coasting vessels it is not only inconvenient to remove the long hold pillars at the frequent loading and discharging operations, but, owing to the possibility of their not being properly replaced, very undesirable. This inconvenience may be overcome by fixing the pillars permanently, but at a considerable athwartship angle, so as to leave quite clear the bottom of the hold (see Fig. 7, Plate 8). Such slanting disposition does not materially reduce their efficiency, for any pressure they take as struts can only act in their line, *i.e.* their inclination does not induce any special bending tendency (they take only that component of the vertical pressure which acts in their direction, the remaining component is a horizontal one, acting along the deck). In some small coasting vessels the hatchways are so broad that the deck plating alongside is reduced to a mere strip, and, being liable, on account of its narrowness, to severe longitudinal stresses, it should be particularly well supported. In such cases pillars are advantageously suppressed in favour of large sweeping bracket plates between the vessel's sides and the deck (Fig. 7).

Art. 143. Wherever permanent heavy weights are carried, **pillars** should be placed **underneath**, to support them. They should be fitted under **large deck houses**, preferably at the corners, where vertical straining tendencies are greatest—a wood deck often developes leakiness at these places. They are particularly necessary under **deck machinery**, the windlass, winches, and cranes; not only to support their weight, but to hold them down when lifting or hauling and to reduce the intense vibration which, when in rapid motion, they convey to the deck. Under the windlass the pillars have a special duty, for when lying at anchor the whole pull of the cables is felt at this part, tending to wrench the windlass from the deck. In high-speed Atlantic liners, when steaming against head seas, the forecastle deck is liable to severe crushing pressures from falling seas, its beams, therefore, are usually particularly well pillared. The turtle-back

type of deck was at one time generally adopted here, for with its convex surface it throws off the water, and is less readily collapsed.

In the case of a **deep tank**, the centre-line bulkhead gives excellent support to the deck forming the top of the tank, against both the downward pressure of cargo above and the upward pressure from water below (Figs. 4, 5, and 6, Plate 24). To hold the deck between this and the side, **side pillars** are fitted, and Lloyd's rules require these to be not less than two frame spaces apart, and to be associated with a fore-and-aft intercostal girder. In many cases, however, it is preferred to fit an extra powerful fore-and-aft girder in conjunction with one or more strong built pillars (Figs. 2 and 5).

Art. 144. The precise **athwartship position of side pillars** is unimportant. In vessels not having a double bottom, they are usually stepped on the side keelsons, for although, as regards the beams, this may place them rather near the centre line, their thrust is brought nearer the keel, on a stiff fore-and-aft part, which affords a good connection clear of the ceiling planking. With an inner bottom they are usually placed so as to divide the beams fairly, and their heels should fall upon floor plates, and not over their lightening holes. In the after hold the **centre-line pillars may step on the tunnel**, or be placed on one side to clear it. The former plan is generally preferred, for it suits better the fixture of shifting boards; it involves the strengthening of the tunnel top, however, to take the thrusting effect of the pillars. This may be done by doubling the tunnel stiffening bars, or by riveting a fore-and-aft angle, tee, or channel bar on the tunnel top; the latter method is convenient in that the bar affords a fixture for the heels of the pillars, but it gives little additional strength to the tunnel top against the collapsing effect of the downward thrust of the pillars. Widely spaced hold beams are pillared like other beams (Fig. 1, Plate 102).

Solid round **pillars are always of rolled iron.** When forming a strut, iron is little inferior to steel, and when, as in ship's pillars, a large margin of strength is provided, the superior qualities of steel would be of little value. Further, as each pillar is often welded at one or both ends, iron, being more easily welded than steel, is more suitable. As a rule, moreover, a second-rate quality of iron is employed (pillar iron), for, as regards mere pillar-like strength, this is as good as the best. Sometimes, however, the quality is much too low, the pillars being so brittle that when struck sideways by cargo they may break short off with little sign of ductility.

The **pillar heads and heels** are formed in different ways. The bars are supplied of suitable length, one for each pillar. The heads shown in Figs. 1 to 4, Plate 13, are formed under the steam hammer, by stamping the end of the bar in a *stamp*, *mould*, or *cress*, made to suit the bulb of the beam; or they may be made in the manner shown in Fig. 25. When the heel steps on deck plating or beams, it may be made as shown in Figs. 21 to 24. The heel shown in Fig. 22 is a separate forging, made by stamping a mass of iron under the steam hammer; they are made in bulk, and are subsequently butt-welded to the pillars, as shown. The heel shown in Fig. 24 is merely a cutting from a thick, flat, iron bar, in which a large hole is punched to receive the end of the pillar; the latter is slightly tapered to enter it, and, both being heated to a welding temperature, the bar is forced into the heel piece and clinched from below. In some cases a similar flat plate is merely butt-welded on the end of the pillar, a hole being punched in it to act as an escape for the slag (Fig. 23). The smith who makes the pillars is provided with a batten template, sometimes one for each pillar, cut exactly to the

length as ascertained from the ship—at that period well advanced and with the beams faired temporarily by shores. Each pillar may thus be made of the precise length, being adjusted, if necessary, by staving up or drawing down while still hot.

The **heads and heels** are usually **connected by two rivets** (Fig. 2, Plate 13), but in large or widely spaced ones **three** become necessary (Fig. 1). Lloyd's rules in this respect require that pillars longer than 24 feet shall have three 1-inch rivets, all others having two, $\frac{7}{8}$ or 1 inch according to their diameter and length[1]. The holes may be drilled, or punched out hot under the steam hammer when making the pillar in the smith's shop. The palms should be substantial, for, as a result of side bending pressures or blows, it is common to find thin palms broken across at the rivet holes. Sometimes the head is formed with a jaw, embracing the bulb of the beam (Fig. 7); this is a particularly efficient fixture, the pillar having a good grip of the beam independently of the rivets. On account of its neat, symmetrical appearance it is often adopted in passenger vessels. To fit such pillars, the head is heated in a fire, so that the jaw, opened to pass over the bulb, may finally be hammered close. Formerly the heels of the pillars were often riveted direct to the tank-top plating; this mode of fixture, however, leads to trouble, for apart from the difficulty of securing close contact of the massive forged heel with the tank top, a slight shock or side pressure on the pillar is sufficient to start the connecting rivets and cause leakiness. The method now always adopted (and specified in Lloyd's rules) is to rivet a short lug, of angle, tee, or bulb bar, to the tank top, and connect the pillar to this (Fig. 10). The various methods of fixing the heels of 'tween-deck pillars are shown in Figs. 11 to 16; the sole plates in Figs. 15 and 16 are fitted when a good bearing for the deck planks is required.

The rivet holes may be punched in the beams in the first instance, corresponding holes being drilled in the pillars by means of a small pattern tin template, bent round the bulb of the beam. Otherwise they may be drilled in the beams after the pillars, previously punched, are fitted in place. It is well that the holes in the beam should be placed well up from the lower edge (near the neutral axis), for, when subjected to excessive force, the lower edge is liable to break through at these holes. The rivet holes to take the heels of the pillars, whether in deck plating, beams, or lugs, are usually drilled after the pillars—previously drilled or punched—are adjusted in place. As there are only two holes in the end of each pillar, care should be observed that they are good holes, that the surfaces fit closely, and that the pillar bears on the lower edge of the beam; sometimes the fit is very inaccurate.

Art. 145. The **portable pillars** at the sides of hatchways are secured in different ways. Usually they are made like the others, but are bolted instead of riveted, the heel, of course, stepping on a lug. Sometimes the head is formed with a pivot or hinge, so that, on withdrawing the heel bolts, the pillar may be swung up to the beam, out of the way of passing cargo, as shown in Fig. 9, Plate 13. Otherwise the heel may be pivoted, between two lugs, or in a special casting, so that, on releasing the head, the pillar may be hinged down on deck, as shown in Figs. 18 and 19. Of course, when the ends of a pillar are pivoted, it loses some of its strength as a strut, but in this respect it is usually amply strong. Another method, sometimes adopted, is to bolt the head in the usual way, but merely step the

[1] Pillars from 10 to 18 feet long, or of $2\frac{3}{8}$ inches and under 4 inches diameter, must have two $\frac{7}{8}$-inch rivets; those from 18 to 24 feet long, *or* 4 inches diameter and over, must have two 1-inch rivets.

heel in a cast-iron socket, as shown in Fig. 17. Otherwise, in special cases, the head may be pivoted, and a wedge-shaped shoe or sole plate fixed on deck (Fig. 20), into which the heel may be driven so that it may exert a thrust on the deck above; a pin may then be fitted behind the heel to keep it from working back. When fixed in either of the last two methods, the pillar only acts as a strut, it does not tie the decks together. This, of course, is objectionable, for the flexibility of the beams may admit of considerable vertical movement. With some kinds of cargo, for instance, shores are used to hold it down and prevent it from shifting during the voyage, and with others of compressible material, screw-jacks are employed to squeeze it into place below the beams, either of which procedures may cause a considerable upward thrust on the deck.

Art. 146. To provide access to the holds and 'tween decks, vertical **ladders** are fitted **at one end of each hatchway.** They are usually formed by a pair of pillars, about a foot apart, drilled to take cross bar-iron steps (Fig. 30, Plate 13). As there are here two pillars in place of one, it is sometimes thought proper to reduce their diameter; this should not be done, however, for they are weakened by the step holes, and as the hatch-end beams have a special duty, they are the better for substantial support. Further, as the ladders are permanently fixed, they are exposed to violent blows from cargo in process of lowering or hoisting from the holds, and, as under such circumstances the one pillar does not assist the other, they should be independently strong and massive; in practice such ladders are frequently bent and broken. The holes are only drilled a short distance in, and, to prevent the steps from bending and drawing out, they should be of large diameter, reduced at the holes. Sometimes slender ladders are fitted with an ordinary pillar alongside, but it is evidently better to fit a stout ladder, which, while acting well as such, may give good support to the hatch-end beam. In the case of trunk hatchways (*i.e.* those of an upper and lower deck conjoined by a casing) the necessary ladderway may be provided as indicated in Figs. 31 or 32. That shown in Fig. 31 is advantageous, in that the steps offer no obstruction to passing cargo.

Art. 147. Tubular pillars are seldom employed in merchant vessels; they are not very much more costly, however, and as their substitution for solid ones would considerably reduce the weight of hull, the gain in carrying capacity might well be thought a sufficient inducement for their adoption. Comparing them with solid pillars: in short ones that would fail by crushing, the strength, weight for weight, is practically the same, for it is governed by the sectional area in either case. But as tubular pillars are of larger diameter, their lateral strength and stiffness is greater, and when it is this that governs the size (as is usually the case with solid pillars) they may evidently, while maintaining ample strength as struts, be much lighter. In the case of long pillars, in which lateral rigidity is the quality principally governing their supporting power, the tubular variety are very superior to the solid. The sizes of tubular pillars given in Lloyd's rules is such that those of ordinary length—say, under 16 feet—are about 40 per cent. lighter than solid ones. A $2\frac{3}{4}$ by $\frac{5}{16}$ inch hollow pillar is regarded as equivalent to a $2\frac{1}{4}$ inch solid one; and an 8 by $\frac{10}{16}$ inch hollow, to a 6 inch solid one. In warships the pillars are always tubular, for here the saving in weight is an important advantage; and, the better to secure it, they are made of large diameter, with thin walls, usually not less than 5 inches diameter, by $\frac{5}{16}$ to $\frac{3}{8}$ inch according to the strength required. In ordinary cargo vessels tubular pillars so slender as this would be too readily damaged by cargo; if struck a hard blow they might be indented and battered, and, of course, they could not be readily repaired.

Tubular pillars are of wrought iron, lap-welded. The heads and heels are solid forgings (Fig. 26, Plate 13); they are stamped in bulk under the steam hammer, and are then welded into the tubes, a tube of suitable length being provided for each pillar. The shank portion of the head and heel is made of a suitable length to scarph about one inch into the tube; it is tapered slightly so as to enter it, and, both parts being raised to a welding temperature, the edge of the tube is hammered down, flush with the soft material of the forging. In these pillars the length is not so readily adjusted, but otherwise, excepting the more extensive welding, they are not more difficult to make than solid ones.

Art. 148. Vessels which carry **grain in bulk** are required, by statute regulations, to have a **central fore-and-aft division** in all holds and 'tween decks in which it is so carried. Its purpose is to mitigate the dangerous heeling effect which would result from shifting of the grain (see Art. 52). It is usually formed in a temporary fashion, by fixing planks, or "*shifting boards*," as they are termed, to the centre-line pillars. Otherwise, in vessels which engage almost exclusively in the grain trade, a permanent centre-line bulkhead of plates and bars may be fitted which, of course, takes the place of centre-line pillars (Figs. 27 to 29, Plate 13). It may be fitted in both the holds and 'tween decks, but portable boards are usually preferred in the latter.

The usual method of fixing the shifting boards, and one for which provision is readily made in all vessels, is to dispose the centre-line pillars slightly zigzag, *i.e.* alternately $1\frac{1}{2}$ inch to port and $1\frac{1}{2}$ inch to starboard, so as to leave a 3-inch fore-and-aft passage into which fore-and-aft boards may be shipped (Plate 106). Otherwise a light bar may be fixed alongside each pillar with a space between for the shifting boards. In large vessels, requiring two rows of pillars, the pillars in both rows may be disposed zigzag, so that shifting boards may be fitted on either side, small 2 feet by 3 feet trimming hatches being provided in the deck over the wing spaces to load the grain through. Formerly, instead of placing the pillars zigzag, two of reduced size were sometimes fitted at each beam. The shifting boards must be fitted against the underside of the deck, and right up to the hatches; for, if not, when the vessel heeled over, the grain, becoming heaped up against the bulkhead, might flow over the top. Many vessels have been lost through incompleteness in the shifting boards, or through their collapse when weak and insecure.

The strength of a **permanent grain bulkhead** must be at least equal to that of the pillars whose place it takes. It is usually built of plates, $\frac{5}{16}$ inch thick, stiffened with angle bars, the size of the vessel's frames (or of reverse-frame size when in the 'tween decks), fitted on each side, two frame spaces apart, back to back, so as to form together a deep web (Fig. 34, Plate 13). In some cases, to minimize the interference with cargo stowage, it is preferred to fit the stiffeners on one side only, one frame space apart (Fig. 35); the stiffening effect, however, is less perfect. Very commonly, instead of double frame angles, it is preferred to fit large single bulb angles of equivalent size, 4 feet apart (Fig. 36). The bulkhead plating is connected to the deck above and to the tank top or keelson, by two small angles (Fig. 27), or by a single large one (Fig. 28). Lloyd's rules require the upper ends of the stiffeners on one side of the bulkhead to be connected to the deck beams; for the latter then receive direct support, and the stiffness of the bulkhead, when thus held square to the deck, is greatly increased. When bulb-angle stiffeners are adopted, it is common to bracket their ends to the tank top and beams (Fig. 29), which, by increasing their efficiency, permits of a reduction in their scantlings,

and of only one small angle connection to the tank top and deck. The bulkhead stops short at the end of each hatchway, portable boards being fitted at these places. Owing, therefore, to its discontinuity, it does not afford any useful fore-and-aft strength to the hull. Compared with mere pillars, however, its supporting and stiffening effect on the deck is very superior; as a diaphragm it possesses perfect rigidity in its own plane—pillars are alike flexible in all directions. For this reason, in **warships**, wherever specially heavy weights are carried, **partial bulkheads** in the form of lightened diaphragms are **substituted for pillars.** They are particularly advantageous under the guns, for when these are fired the deck under them and beyond the muzzle tends to jump upwards, so that, were it held only by ordinary pillars, the connecting rivets would at once be shorn. In the machinery space the **side-bunker bulkheads** and the casings may render unnecessary the fitting of side pillars at this part, but in such cases Lloyd's rules require them to be constructed in the substantial manner just described for centre-line grain bulkheads.

CHAPTER XIII.

Art. 149. A **deck** may serve several **purposes.** The upper one is, of course, necessary as a watertight covering for the hull; others, however, may be required as platforms for the convenient working of the vessel, as intermediate platforms for the stowage of cargo, and as horizontal diaphragms giving longitudinal strength and general rigidity to the hull. The deck of a small vessel need only be of wood; usually, however, a plated one is preferred, for, while equally suitable, it is more durable, and adds to the structural strength of the hull. As dimensions increase, the strength of the hull requires the upper deck to be plated, all fore-and-aft, or only for half length amidships; and, finally, a second, and even a third deck may be necessary. Of course, when the special character of a wood deck is desired, as in passenger vessels, the plating may be sheathed with wood (Plate 107).

Art. 150. Whether or not a plated deck is needed, the marginal part of one, the **stringer plate**, is required on all tiers of beams; and besides this, fore-and-aft **tie plates**, to hold the beams fixedly one with another. A deck stringer plate by itself is useful in several ways. As regards the beams, it holds them square with the side (Fig. 7, Plate 1), and, being united all fore and aft to the shell, binds them thereto independently of the beam knees, *i.e.* it affects a thorough incorporation of the deck with the sides of the hull. It gives continuous transverse rigidity to the vessel's sides, and contributes longitudinal strength. In the latter respect the upper-deck stringer is most useful, for, in conjunction with the thick sheer strake, it effects a concentration of fore-and-aft material at the gunwale, and gives lateral stiffness to the important sheer strake, without which it would be very inefficient (see Art. 37).

The **scantlings of the stringer plate** vary with each deck. As that on the upper deck has the most important duties, it is the most substantial; its breadth and thickness depend not merely on the size of the vessel, but also on the proportion of length to depth; for, of course, although a vessel may be small in tonnage, she may be so long and shallow as to require superior longitudinal strength; and similarly in the case of breadth, but, as a rule, this is never disproportionately small. A lower-deck stringer is not so much required for longitudinal strength, and as its duties are, therefore, lighter, it is less substantial, its sectional area being from one-half to two-thirds that of the upper deck. In vessels of three-deck type the third deck —if one is fitted—is regarded as the lower one, the stringer of the second being identical with that of the upper. Where there is a fourth tier of beams (sometimes termed "orlop beams"), its stringer plate is made still lighter, its sectional area being about 75 per cent. of that of the lower deck above it. In spar or awning-deck vessels, the second deck is regarded as the main deck proper, and so it is here that the heaviest stringer is placed, the stringer of the deck above being reduced, slightly in the case of a spar deck, but very considerably in that of an awning deck. The stringer plates

of light deck erections—poop, bridge, or forecastle—have a sectional area about half that of the stringer on the deck immediately below them.

Like all other parts, the deck stringer plates taper towards the bow and stern; their full scantlings are maintained for half length amidships, thence they diminish both in breadth and thickness, their sectional area at the ends being about 50 or 60 per cent. less than amidships (Plate 86). Deck plating is usually thinner than the stringer plate by $\frac{3}{20}$ or $\frac{4}{20}$ inch; the extra thickness in the latter is necessary because, as it is united to, and must co-operate with, the thick and important sheer strake, it should have massiveness in some degree proportionate. In view, however, of the strength which the stringer gains when its free edge is conjoined to deck plating, and of the general strengthening effect of the latter, it is usual, when the deck is plated, to reduce its breadth, making it 1 inch broad for every 7 feet in the length of the ship (Lloyd's rules permit of this, provided only one deck requires to be plated). In vessels of large size the stringer plate may be very wide, perhaps 7 feet; if so, it is well to fit it in two strakes, because not only would plates of such width necessarily be short, but their numerous long end joints would form transverse lines of marked weakness; when fitted in two strakes the plates may be longer and their end joints fewer, and, as the latter are 50 per cent. narrower, their weakening effect is reduced by a like amount. By the rules of the British Corporation, the upper-deck stringer is made narrow and very thick, being practically of the same scantlings as the sheer strake. In a vessel 600 feet long, for instance, it is 48 by $\frac{23}{20}$ inch, the deck plating alongside being $\frac{14}{20}$ inch; and in one 300 feet long, 40 by $\frac{13}{20}$ inch, the deck being $\frac{6}{20}$ and $\frac{7}{20}$ inch. By these rules a fully plated second deck is not required until a vessel's length exceeds 470 feet (Art. 153).

Where **stringer plates or plated decks meet transverse bulkheads**, it is the latter that give way, for they are not injured by the discontinuity, whereas deck plating, being liable to fore-and-aft stress, might be, seriously. In the case of an unplated lower deck the deck planks abut on either side, as shown in Figs. 1 to 4, Plate 21; and if the stringer pierces the bulkhead the marginal plate of the latter is slotted or severed. Sometimes it is advantageous to cut a lower-deck stringer at the bulkheads, especially when these form the ends of deep ballast tanks, for by maintaining their integrity watertightness is more easily secured. A lower-deck stringer is not important as regards longitudinal strength, and where it is severed at a bulkhead its strength may be sufficiently maintained by increasing its width by bracket plates, so as to secure an extensive connection on either side of the bulkhead. The connection should be made by double angles, or by an extra large single one.

Art. 151. The outer **edge of a deck stringer plate** at the ship's side is, of course, a fairly **curved line**; the inner one, however, may or may not be so; very commonly it is **irregular**, owing to the individual plates of which it is composed being cut each with a straight inner edge (Plate 86). This is done merely to simplify the work, for to shear a plate to a hollow and varying curve is awkward. If conjoined to deck plating, slight variations in the breadth of the stringer plate are unimportant, but if it stands alone they may be prejudicial, because the contiguity of narrow and wide places tends to concentration and localization of stress at the former; the prejudicial effect being intensified, moreover, by the presence at each narrow place of a joint, in itself a point of weakness. By making a fair inner edge, the excess of breadth and of strength between the joints is removed, weight is saved, and the efficiency of the structure improved. Nevertheless, the omission to do this is not usually prejudicial, for the side

of the ship amidships, where longitudinal strength is most required, is generally straight. Other matters in connection with stringer plates will be found in Art. 517.

In order to secure greater **uniformity in the strength of a deck-stringer plate**, it has been proposed to pierce it, between the beams, with long holes, of just such a width as to reduce locally the sectional area to what it is at each joint, or at each row of beam rivet holes. The principle involved may be illustrated by the case of a chain cable; if, say, in a 2-inch cable there were one 1-inch link, the strength against a suddenly applied stress would be less than if all links were 1 inch; for in the former all the straining effect would be concentrated at the one weak link—just as in the familiar case of a notched stick. If all the links were weak, then, as all would experience the same stress per square inch, they would all stretch alike, and thus the chain would be more likely to endure a sudden stress without injury. It is evident, therefore, that the cutting away of the material of a stringer plate where there is a superabundance of strength would produce a similar approximation to the desirable condition of perfect uniformity in sectional area. For the same purpose and with a view to reducing the weight of structural material, it has been proposed to apply the above principle to plated decks,[1] by not jointing the ends of the plates, but fitting them some distance apart, in such a way as to reduce the sectional area (taken across the whole breadth of the deck) between the beams to what it is through a line of beam rivet holes; if the latter were eight diameters apart, then every eighth strake between the same two beams might have an open joint. Of course, although the above is theoretically correct as regards tensional stress, it would greatly reduce the capabilities of the deck (or stringer plate) under compression, and its general stiffness as a diaphragm; also, it wrongly assumes the longitudinal stress to be applied with such precision as to affect uniformly every part.

Art. 152. In the absence of deck plating, **fore-and-aft tie plates** are fitted on each tier of beams, one on either side (see Fig. 6, Plate 10, and Figs. 1 and 2, Plate 86). Their purpose is to support the beams laterally, just as the pillars do vertically, so that by tying each one to its neighbour they may check side straining tendencies. When a wood deck is laid on the beams, it might appear that the extensive bolt connection to each one might hold them sufficiently rigidly without tie plates. But it is undesirable in a steel or iron vessel to impose any structural duty on the woodwork. Although in a new vessel the deck bolts might clamp the beams with sufficient rigidity, in course of time they would work loose; in old ships it is common to find that the deck planks have lifted from the beams, often extensively, owing to the formation of a thick intermediate scale of rust; and it is evident, under such circumstances, that, should the beams develop any side straining tendencies, the deck bolting would speedily suffer, and the consequent straining of the planks would start the caulking and cause leakiness. But, moreover, the wood deck planks may not be continuous; at the end bulkheads of deck erections, they are all severed, and a large number are cut at each hatchway, and it is evident that in such cases they must be very ineffective as fore-and-aft ties (Fig. 18, Plate 56). Of course, in a wood deck itself such discontinuities are unimportant, so long as no structural duty is demanded of it.

The tie plates are so disposed as to pass alongside each hatchway, for they then assist the coaming plates in forming a rigid frame around the opening (see Figs. 5 and 6, Plate 58, and Plate 86). They may be regarded as a horizontal coaming, giving lateral stiffness to the vertical one, offering

[1] See a paper by Sir Nathaniel Barnaby, *Trans. Institution of Naval Architects*, 1866.

a more extensive connection for the ends of the half-beams, and providing against their thrusting effect. The necessity for a substantial coaming, both vertical and horizontal, increases with the length of the hatchway, *i.e.* the number of beams severed. Lloyd's rules require, when its length exceeds 16 feet, that the contiguous tie plates shall be of double breadth (Fig. 2, Plate 86). If the hatchway is 22 feet long, the whole deck on either side of it must be plated (Fig. 1). If, to suit the hatchways, the tie plates do not run straight fore and aft, they may be angled; or where there is a considerable divergence of line, they may be conjoined by local deck plating, or their ends may be scarphed a distance of at least two beam spaces (Fig. 2, Plate 86).

The breadth of the tie plates is usually the same on all decks, being about one-half that required for the light-scantlinged lower-deck stringer plates; their thickness is that of the stringer plate of their particular deck. In cases where, for convenience of cargo stowage, a lower tier of beams may not have a deck laid thereon, ordinary tie plates are somewhat obstructive, and they may be bent down between the beams by heavy weights of cargo. In such cases, therefore, it is sometimes preferred to substitute a double-angle stringer, which, being narrow, is less in the way, and possesses the vertical stiffness lacking in the former (Plate 101). The tie plates are severed at the transverse bulkheads, and the strength of the connection thereto should, of course, be equal to that of their end joints, these being double riveted.

Art. 153. Diagonal ties are fitted on the upper-deck beams of sailing-ships which are not of a size to require a plated deck (Fig. 2, Plate 86). Their purpose, as noticed in Art. 37, is to check any tendency to parallel straining movement in the beams, and to hold them at fixed angle with the side, and thereby give rigidity to the deck against lateral bending tendencies in its own plane. In steamers they are rarely fitted, for these, unlike sailing-ships, are not subject to severe lateral bending forces. When they are fitted, they so assist the stringer in its duty of holding the beams square to the side, that a reduction in its normal breadth becomes admissible, the accompanying loss of longitudinal strength being (in a small steamer not subject to severe longitudinal stresses) more than counterbalanced by the superior rigidity of the deck surface. **Lloyd's rules** provide for this, for they permit of the breadth of the stringer in such cases being reduced by that of the diagonal tie plates. In practice, however, this distribution of material is seldom adopted, for the greater weight of hull, and the increased expense due to the added parts, is not warranted by any appreciable gain in efficiency. By the rules of the **British Corporation**, a second entirely plated deck is not required until a length of 470 feet is attained. In a vessel just under this, while the upper deck is plated (with $\frac{9}{20}$ inch plating), the second need only have marginal deck plating, in the form of a broad, thick stringer plate (having its inner edge parallel to the centre line) 13 feet wide by $\frac{12}{20}$ inch thick. In smaller vessels a less wide stringer suffices, but in all cases diagonal tie plates are required on the unplated beams between the stringers. And in way of large deck openings (wider than 40 per cent. of the vessel's beam, or longer than 10 per cent. of her length) the half-beams must be plated between the stringer and the opening.

In small **sailing-ships** (less than 15,000 plating numeral) the strength and rigidity of the hull generally is such that **diagonal deck ties** need only be fitted in way of the masts (Fig. 1, Plate 86). In larger ships they must be fitted all fore and aft (Fig. 2); in still larger the upper deck is plated, either all fore and aft or only amidships; if the latter, diagonal ties are

fitted at the ends (Fig. 3). In all sailing-ships, small or large, diagonal ties must be fitted in way of each mast, on whatever deck these may be wedged (Fig. 1). Their purpose is to distribute the **thrust of the mast,** in whatever direction it may occur. The heeling effect of the masts may at times be so severe as to force the vessel over on her beam ends. Let it be imagined, now, that this force only acted on the two mast beams, *i.e.* the one before and abaft the mast, it is clear that these, being subjected to an intense push to leeward, would tend to move endwise and forward relatively to their neighbours, so that the rivets connecting them to the frames and stringers, and the deck bolting and caulking might suffer under the intense stress. If, now, the same side heeling force, instead of being concentrated on two beams, were distributed over a number, the intense stresses would disappear. Such distribution is at once effected by fitting a pair of diagonals at each mast, for then a whole group of beams, being united in a manner not permitting of independent parallel movement, would be compelled to strain together. Of course, the heeling effect of a mast does not all occur at the mast hole; the greater part of it, indeed, is transmitted by the windward shrouds, which indirectly affect a number of beams. Straining effects due to excessive heeling forces acting through the masts are occasionally observed in loosening of the rivets at the ends of the beams, and starting of the deck caulking in the vicinity of the mast hole.

Diagonal tie plates are of the same breadth and thickness as the fore-and-aft ones. When fitted all fore and aft they are arranged in pairs, crossing one another at an angle of about 90°, in such a way that every beam falls under their influence, except, of course, those beams at the bow and stern, where the converging stringer plates give the necessary bracing effect. If disposed at a greater angle than 90°, fewer pairs might suffice to cover all beams, but their bracing effect would be less perfect. It is not necessary that they should be arranged with perfect symmetry; where they meet local deck plating a considerable divergence may be made. At their crossing points they should be butt-jointed or overlapped in such a way that the check cut in the deck planks may not be deeper than the thickness of one plate.

Art. 154. Numerous **local patches of deck plating** are required. The deck beams under the galley or donkey-boiler house are always plated, cemented, and tiled; in many of the early iron vessels the galley floor was formed by laying cement on the top of the wood deck, but the latter, when covered up and subjected to heat in this way, invariably decays. The mast-hole plate is described in Art. 378. Bolted to the deck, there are various appliances whose purpose in the working of the ship subjects them to intense stress; there are the winches, windlass, capstans, cable stoppers, mooring and towing bitts, stay plates, steering gear, etc. The deck beams under these are always plated, for if the holding-down bolts merely passed through the wood planks, the forces to which they are liable would strain the deck bolting and start the caulking; and, as a result of the independent straining and imperfect co-operation of the holding-down bolts, the cast-iron bed-plate of the bollard, or whatever it was, might fracture (Art. 362). The plating binds consecutive beams together, and offers a wide and extensive base of attachment, such that straining must involve a simultaneous movement of beams, plating, and deck.

When **deck planks** abut against the hatch coamings, or on the end bulkhead of a deck house, there must be a **ledge,** at least 6 inches wide, **to support their ends** and admit of the bolts being placed a sufficient distance therefrom (Fig. 18, Plate 56, and Fig. 5, Plate 58). When an athwartship deck plank is fitted, the supporting ledge plate must, of course,

be extra wide (Fig. 6, Plate 58). When a bulkhead against which deck planks abut extends right across the ship, as at the end of a poop or bridge house, it is well that the entire beam space should be plated, for with so many planks severed in one line, a rigid foundation is desirable to check the tendency to local straining of the deck surface (Fig. 2, Plate 86). Similarly, in the case of long central deck houses, the beam space under their ends should be plated, and the beams well pillared at this point; when this is not done there may be trouble from leakiness, through starting of the caulking, consequent on vertical straining of the planks at the ends of the long rigid deck house.

Art. 155. Lloyd's rules present a tabulated statement of their **requirements as to plated decks.** They vary not only with the general size of the vessel, but according to the proportion which the length bears to the depth (see Plate 4). Thus, for example, in all vessels over a certain size (23,000 plating numeral) the upper deck must be plated amidships for at least half length; but if, in such, the length should exceed 10 times the depth, it must be plated all fore and aft. In still larger (35,000 plating numeral), when the length exceeds 10 depths, the second deck, in addition, must be plated for half length; and when the length exceeds 11 depths, all fore and aft. In smaller vessels deck plating only becomes necessary when a certain proportion of length is exceeded, 13 depths in the case of one having a plating numeral of 11,000. Account is also taken of possible cases of disproportionately small beam, but modern vessels are not disproportionate in this respect.

The principles governing the above requirements are considered in Art. 9. Summarising, briefly: the greater a vessel's length compared with her depth, the more does she resemble a shallow, and, therefore, a relatively weak girder, and so, of course, the more the necessity for greater efficiency in her girder-like design, *i.e.* the top flange should be well represented by deck plating. And this is the more imperative on account of the method of assigning the general scantlings, for, by the system of numerals adopted in Lloyd's rules, a reduction in the depth and breadth (*i.e.* a reduction in the general size or tonnage of the vessel), while rendering more acute the girder-like stresses to which the hull is liable, is accompanied by a general reduction in scantlings. In the case of a large vessel, deck plating becomes necessary for the general rigidity of the hull, irrespective of her proportions. In a small vessel the scantlings of the hull are usually such as to give a high degree of strength and rigidity. In a large vessel of similar design it would be impracticable (with a view to securing the same degree of strength and rigidity) to increase the scantlings proportionately to the weight carried and to the bending and straining forces to which the hull is exposed, for the weight of the hull would be excessive. In practice, however, strength and rigidity approximating to that prevailing in a small vessel may be secured with a comparatively small increase of scantlings, by introducing special distinctive parts, *i.e.* more plated decks, more tiers of beams or web frames, and more transverse bulkheads. Plated decks and bulkheads form horizontal and vertical diaphragms, perfectly rigid in their own plane; their introduction, therefore, at once imparts great and widespread rigidity to the hull. As a familiar illustration, the stiffening effect of cross divisions in a *slender* box may be suggested.

When, with increased dimensions, the necessity for deck plating first presents itself, only the 'midship portion need be plated, for, of course, it is here that the hull is most severely tried, both by longitudinal and transverse forces. The plating does not terminate square across, for this would result in a serious discontinuity in strength and stiffness; it is tapered beyond the

half-length, for a further one-eighth of the length (Fig. 3, Plate 86). It runs off into the stringer, for, owing to its union with the side, it is the marginal part of the deck that is most effective—isolated central plating would be comparatively useless. When plated all fore and aft, the portions towards the bow and stern, where longitudinal stresses practically disappear, are evidently of little service in this respect; but not so when regarded as parts of a horizontal diaphragm, giving general rigidity to the hull against the local stresses of a dynamic character, to which these parts are particularly liable (see Art. 107). By Lloyd's rules, steel decks vary in thickness from $\frac{6}{20}$ inch in a small vessel to $\frac{10}{20}$ inch in a large one; and for iron decks, $\frac{6}{16}$ and $\frac{10}{16}$ inch. If only $\frac{6}{20}$ inch, the full thickness is maintained all fore and aft; if thicker, the portions beyond the half length amidships are $\frac{1}{20}$ inch thinner; or if so thick as $\frac{10}{20}$ inch they may taper by $\frac{2}{20}$ inch.

Art. 156. The longitudinal strength afforded by **deck plating** is measured by its smallest breadth or sectional area; it therefore, depends on how much of it is **cut away by the 'midship hatchways or machinery openings.** If these are so wide as to leave only a narrow strip on either side, the hull may obtain little strength from the deck; and if strength is particularly required, **compensation** must be made by increasing the thickness of the reduced part. The extent of such compensation depends on how great is the need for longitudinal strength, and on how much this is prejudiced by the opening. When the size and proportions of a vessel are so moderate as only to call for 'midship deck plating, it may be unnecessary to compensate for that removed by the openings, for, there being no need for special longitudinal strength, the strip of deck plating on either side of the hatchways may afford ample; this might, indeed, be regarded as the essential part of the deck, the central areas of plating lying between the openings being introduced merely to complete its diaphragm-like character.

In practice the matter is regarded in this way, for although compensation is usually made by thickening the deck plating, the addition does not equal the sectional area cut away by the openings. The necessity for compensation is, of course, most felt in way of the 'midship openings; if these are not exceptionally wide, and if longitudinal strength is not specially called for, an increase of $\frac{1}{20}$ inch in the thickness of the adjoining strake of plating is usually sufficient (Fig. 4, Plate 86); with greater breadth of opening, or greater need of longitudinal strength, it may be made much thicker. In large vessels, having several plated decks, in all of which the breadth is reduced by large machinery openings, special compensation may be necessary; all the plating on either side of the upper deck may be thickened or locally doubled, and that of the decks below reinforced to a lesser extent. In such vessels the lowest deck—it may be the third or fourth—may be entirely suppressed in way of the machinery; and if plated before and abaft this, as is often the case, there may exist marked discontinuities in the strength; but a plated third or fourth deck is not usually essential for structural purposes; as a diaphragm it affords useful rigidity to the hull, and where suppressed in way of the machinery space its effect, as regards transverse rigidity, may be maintained by fitting additional web frames and side stringers. The marginal part of a deck suppressed in this way is usually retained as a wide hold stringer, into which the deck plating before and abaft it is more or less gradually tapered. In some large Atlantic liners an open box-girder formation is adopted for such stringers, formed of two heavy stringer plates about 18 inches apart, connected by transverse webs and supported by brackets. The practice already noticed, of fitting the half-beams at the sides of hatchways on every frame in place

of alternate ones, is an important means of insuring superior efficiency in the deck plating, for the valuable feature of a fair surface is assured, and the resistance of the plating to compressive stresses is practically doubled (Art. 125).

Art. 157. The strake of plating adjacent to the **machinery openings** is an important one, for, owing to the lateral stiffness secured by its union with the vertical casing, it is more capable than the others in resisting longitudinal stresses. It forms, with the coaming plate of the casing, a fore-and-aft T girder, whose special duty is to uphold the inner ends of the severed beams (half-beams), and, with them, the entire marginal part of the deck (Fig. 5, Plate 8, and Figs. 1, 3, and 5, Plate 27). The machinery casings are not usually regarded as structural parts, and so are of thin plating; their coaming plates, however, having the special duty just noticed, are made more substantial. In large high-powered steamers, which are subject to severe longitudinal and transverse stresses and vibrating effects from the machinery, an efficient design of the decks at the sides of the long machinery casings, where prejudiced by the severance of so many of its supporting beams, is very important. In some of the earlier vessels of this class, to support the ends of the half-beams, powerful fore-and-aft I beams were fitted, spanning the distance between through-beams of similar construction. Now, the better plan is usually adopted of improving the efficiency of the girder formed naturally by the coaming plate and the conjoined strake of deck plating; by increasing the thickness of these parts, fitting heavy angle bars above and below the beams, as shown in Fig. 1, Plate 27, and in some cases connecting the coaming to the deck by bracket plates (Fig. 5, Plate 8).

Art. 158. Besides the cargo and machinery hatchways, numerous **smaller openings** are cut in the deck plating—coaling hatches, trimming hatches, ventilators, companionways, etc. As these are usually small, they reduce so little the longitudinal strength of the deck as not to call for compensation. In most vessels, however, side **coaling hatches**, about 2 feet wide, are cut in the deck alongside of the machinery openings, and as the deck here is already reduced in breadth, any further diminution of its sectional area is inadmissible. **Compensation** is, therefore, provided by fitting a **doubling plate** alongside the opening, having a similar cross sectional area to the material cut away (see Fig. 2, Plate 58, and Fig. 4, Plate 86). This is practically equivalent to taking the plate removed to make the hole, and placing it alongside; but, of course, it must be extended past the ends of the opening, so that at no place more than another may a transverse fracture have less material to sever. The extension of the doubling must be such that should a fracture (seeking to avail itself of the opening and yet avoid the doubling) pass by a devious course around its ends, it would, in so doing, be compelled to sever at least the same amount of material as if it passed straight across, through the doubling. A devious or slanting line of fracture would, of course, involve the severance of more material than a straight-across one, how much more depending on the extent of the divergence. It follows, therefore, that a doubling patch, while maintaining its efficiency, may be tapered in width towards its ends, for although here of smaller sectional area, a fracture could not avail itself of the circumstance without adopting the less easy circuitous route. The taper should occur at the side of the doubling remote from the opening, for then, should a fracture begin, say, at the corner of the opening, it would have to start away in a fore-and-aft direction—an unlikely course for one due to longitudinal stress (Fig. 2, Plate 58). Of course, a fracture due to excessive longitudinal tension does

not usually creep along in the manner suggested, but occurs practically simultaneously; if it did creep along, it would be difficult to provide against, for the breaking or tearing stress, being momentarily concentrated at the end of the fracture, would not be greatly hindered by the necessity of following a devious course.

The doubling plate should, of course, be fitted close to the edge of the opening, so as to stiffen it and offer a prompt resistance to fracture of a tearing nature. Sometimes it is made entirely to surround the opening, but, unless for its stiffening effect on the edges, it is then no more efficient; the free edges of such openings are usually protected and stiffened by an angle bar or coaming (Figs. 1 and 2, Plate 58, and Fig. 1, Plate 29); and if a compensating doubling plate is not fitted, the angle bar should be of large scantlings and have turned or welded corners. Sometimes where, for facility in coaling, a number of small openings are placed close together in the same strake, instead of fitting separate doublings, the contiguous strake of plating, or the same one (when not all cut away), is greatly thickened; local doublings, however, are advantageous in that they give rise to smaller and less sudden variations in sectional area. The stringer plate is so important a part that care should be observed nowhere to weaken it by holes. Its integrity is not usually disturbed, but sometimes, in the case of a lower deck, coaling holes are cut in it for filling the lower bunkers directly through ports in the vessel's side (Figs. 3 and 6, Plate 60).

In the case of **large deck openings,** small **doubling plates are fitted at the corners,** as shown in Fig. 23, Plate 58, and Fig. 4, Plate 86. Besides the loss of longitudinal strength due to the opening, the sharp corners have an additional weakening effect, in that, nick-like, they induce a localization of stress; they form convenient starting points for fracture, especially when of a tearing nature, and, of course, a double thickness in the deck plating, at the corners, checks this. When a doubling plate is fitted for longitudinal strength alongside of an opening in the deck or shell, the above reinforcing effect may be simply secured by locally increasing its width so that it may surround the corners (see Fig. 4, Plate 60). In other cases the effect of a doubling may be secured by placing the joints of the strake alongside the hatchway, at the corners, and forming them with a long overlap, as shown at A, B, Fig. 23, Plate 58. As a further means of checking any tendency to tear at the corners, it is common, in important deck openings and openings in the shell such as cargo ports, to make the corners round instead of square, for then, of course, their nick-like effect is reduced (Plate 60).

Art. 159. In vessels whose dimensions or proportions may not call for a plated deck, it may be necessary, if the cargo **hatchways** or machinery openings are **exceptionally long,** to plate the deck beams on either side (see Fig. 1, Plate 86). Lloyd's rules require this if a hatchway is 22 feet long and above; and in the case of the engine and boiler openings if their combined length exceeds 30 feet, or if either is longer than 15 feet. The plating is extended past the opening, tapering into the stringer plate. Its purpose is to compensate for the severance of so many consecutive deck beams, by distributing the supporting effect of those which do go across, and by giving lateral rigidity to the vessel's side and deck. When large hatchways are adjacent to one another, leaving only two or three cross beams between, the latter should be plated over from stringer to stringer, for, in the absence of so many adjacent beams, a special duty falls upon these, and were they not reinforced by plating, they would be free to strain individually in the plane of the deck, and would have little influence in checking relative straining of the two isolated stringer plates of the kind described in Art. 37.

Art. 160. A **raised quarter-deck** is simply the after portion of the upper deck raised to a higher level, usually from 3 to 4 feet (Plate 14, and Fig. 2, Plate 26, and Plate 109). Where the step or break occurs, the enclosure is made good by a transverse bulkhead. As the break in the continuity of the upper deck may greatly injure the longitudinal strength of the hull, special care must be observed in the structural design at this part. The extent of the reinforcements depends on the position of the break (whether near or remote from the 'midship region), on how great the necessity for longitudinal strength, and how much of it the deck is expected to afford.

In the case of the **short quarter-decks** sometimes fitted in small ships, the break occurs so remote from 'midships as to have little prejudicial effect on the longitudinal strength. It may, therefore, be amply maintained merely by scarphing the stringer plate of the upper deck below that of the quarter-deck, a distance of 8 feet or so, tapering it as shown in Fig. 4, Plate 14, and by doubling the sheer strake across the break. In these vessels there is usually a cabin below the quarter-deck, in which case the break bulkhead extends down to the cabin deck, the upper deck abutting on the fore side of it. To support the ends of the deck planks, and at the same time stiffen the bulkhead, a ledge or shelf plate is fitted across it, which, if not extended to the adjacent beam, should be supported by brackets. In small steamers a similar arrangement is sometimes adopted at the forecastle, which is then designated a "*sunk forecastle.*"

In small steamers of **well-deck type**, the usual arrangement of raised quarter-deck is shown in Fig. 2, Plate 14. Here more extensive **structural reinforcements** are necessary, for not only does the break occur nearer 'midships, but the discontinuity is more pronounced, because of the stoppage of the bridge deck and its side plating. If the vessel is not very large (less than 24,000 plating numeral) and her length does not exceed 11 depths, Lloyd's rules require the upper-deck stringer to extend abaft the break about 14 feet; the quarter-deck stringer to extend before it some 8 feet; the strake of shell plating above the sheer strake to be locally doubled; the bridge side plating to be continued 3 or 4 feet abaft the break so as to form part of the quarter-deck bulwark, and the bridge-deck stringer plate to extend abaft it so as to form a bracket plate to the same. Owing to the increase in the vessel's depth below the quarter-deck, there is usually an additional hold stringer here, and, of course, this also must scarph beyond the break.

Further modifications become necessary **if the upper and quarter-decks are plated.** If both of these large plated surfaces merely abutted on the break bulkhead, there would be no fore-and-aft continuity; under longitudinal stress the conjoining bulkhead would not prevent them from pulling asunder, as shown in Fig. 3, Plate 14. To secure an effective union there must be a connecting medium having rigidity under a fore-and-aft pull. This is provided by fitting diamond-shaped **diaphragms** between the two decks, formed each by two bracket plates, one connecting the upper deck to the bulkhead, and the other, immediately abaft it, connecting the quarter-deck to the same (Fig. 2). As these brackets have to transmit any longitudinal pull of the one deck to the other, they must be securely connected by double angles throughout.

In larger vessels (over 24,000 plating numeral), or in those which, being of **extreme proportions** (over 11 depths), require more perfect longitudinal strength, instead of merely scarphing the deck stringer plates, **the two decks are scarphed**, right across the ship, the length of the overlap varying from 4 to 10 feet, according to the vessel's dimensions (Figs. 5

and 7, Plate 14). Now, it is evident that the mere overlap of these two independent plated surfaces would not constitute a union; there must be some rigid connecting medium. In the case of the marginal parts (the stringers) this is formed by the shell plating, for as both parts are held by it, they cannot draw asunder. To connect similarly the central portions, diaphragm plates are introduced between the overlap of the two decks, four or five in number, strongly connected to the decks and bulkhead by double angles, and stiffened on their free after edge. Further, in order that the bridge deck may be compelled to assist in maintaining the longitudinal strength at this part, vertical web plates—about 18 inches deep—are introduced between it and the upper deck, in front of the break bulkhead, so as to form a sort of yoke for the three parts, the quarter deck on the one side and the bridge and upper deck on the other. They are placed immediately in front of each diaphragm plate, so as to check any tripping tendency which might develop as a result of fore-and-aft straining of the two decks —such as is depicted in Fig. 6.

In vessels of the above type, the **break bulkhead** is usually the bulkhead at the after end of the engine room (Fig. 7, Plate 14, and Plate 109). Now, at this part the upper deck may exist only as a marginal part on either side of the machinery opening, in which case only these parts can scarph properly with the quarter deck, the central patch of upper-deck plating abaft the bulkhead being, by itself, of little value. Lloyd's rules permit of this **marginal scarph** in small vessels, but if over 13 depths in length, or 20,000 plating numeral, it must be of full width, in which case it is necessary that the deck should be of full width for some distance (8 feet) before the bulkhead (Fig. 1, Plate 14). Even with these numerous reinforcements, local straining at the break of large quarter-deck vessels is not uncommon. It is usually indicated by straining of the end joints of the topside shell plating, of the marginal parts of the quarter-deck, and of its connection to the bulkhead and sides. To guard against it the greatest care must be observed, not only in the structural design, but in the riveting of the joints in the neighbourhood of the break.

Art. 161. The different **strakes of deck plating** may be arranged **clinker** fashion or **in-and-out,** or they may be **joggled** (see Plates 104 and 105). If the deck is wood sheathed, the clinker arrangement is objectionable in that, as the planks must be of varying thickness, there is considerable waste. When not wood sheathed, the clinker system is better than the in-and-out, in that, by fitting short tapered liners, weight and three-ply riveting is avoided, and water may not lodge at the edges, but all flow to the gunwale. In rare cases, when **chequered plating** is adopted, the strakes are worked edge-to edge, the connecting edge strips being fitted in short lengths between the beams, so as to avoid liners and three-ply riveting. This is a somewhat costly system, for it involves double the amount of seam riveting, and more careful workmanship is required to secure sound, watertight work. It is advantageous with chequered plating, because, when overlapped, the projecting ribs prevent uniform contact of the faying surfaces. They might be chipped off at the landings, but to save trouble this is not usually done, the blows of the riveting hammers bringing the edges of the plates, gunwale bars, etc., sufficiently close for caulking purposes. When deck plating is joggled, the joggling should be discontinued in way of all athwartship angle bars; otherwise liners must be fitted on the outer strakes, having their ends specially tapered to fit the joggle (see Fig. 23, Plate 15).

The strakes of deck plating are often very broad—6 feet or more; they run in straight fore-and-aft lines, but between the ends of adjacent

hatchways they are often arranged athwartship, if such disposition results in fewer plates and less riveting. The landing edges are single riveted. The end joints are usually lapped, being double riveted, for the 'midship half length, and single beyond. Those of the more important stringer plate are treble riveted for half-length amidships (except in very small vessels), and beyond this double; in large vessels they are treble riveted for three-quarter length. In very large (over 28,000 plating numeral), still greater efficiency is secured by connecting those of the upper-deck stringer amidships with double straps, treble riveted; or by quadruple riveted lap joints; and those of the important strake of plating alongside the large machinery openings may be similarly treated.

Art. 162. When a plated deck is sheathed with wood it need not be caulked, for the **caulking** of the wood sheathing makes the whole watertight: if this were defective, so that water had access between the planking and the plating, it would readily find its way below, through the numerous bolt holes, pipe fittings, etc., which pass loosely through the plating. Sometimes, with a view to securing watertightness independently of the caulking of the sheathing, the plating is also caulked, and the nuts of the deck bolts hove up on gromets (*i.e.* a thread of oakum dipped in white lead and wound around the bolt); but even when this is done, permanent watertightness cannot be relied on. There is an actual disadvantage in attempting to make the two surfaces independently watertight, for should the caulking of the wood deck become defective at any place, the long distance that water might travel between the two before finding egress, would render more difficult the precise localization of the defective caulking for immediate repair. In cases where absolute watertightness, independently of the sheathing, is desired, as in the shell plating of sheathed warships, the bolt holes are tapped through the plating, so that the bolts may be screwed tightly into them (Art. 470)

Art. 163. The subject of **wood decks** is dealt with in Art. 335 onwards, but it will be well to notice here the **advantages and disadvantages** of a wood deck *versus* one of steel or iron. A wood deck is pleasanter to walk upon, especially in tropical climates where plating becomes unbearably hot; also, as noticed later, it permits of a gutter waterway, and when well kept has a handsome appearance. Although, in a cargo vessel, these may be unimportant matters, they are not so in those carrying passengers; here an uncovered plated deck is practically inadmissible. A wood deck is also advantageous in that, being a good nonconductor of heat, it does not transmit the scorching heat of tropical suns to the living spaces or cargo holds below. In the case of a plated deck, a small reduction in its temperature causes a deposition of dew on its surface, especially on the lower one which is in contact with the warm, moist atmosphere of the hold or cabins—just as moisture condenses on a glass of cold water in a warm room. This "*sweating*," as it is termed, is very objectionable, for as the moisture accumulates, it drops and trickles downwards, just as if the deck were leaking (see Art. 467). When the deck is of wood there is no sweating. When a plated deck is sheathed, the tendency to sweat is much reduced, for as the plating is not exposed to the outer atmosphere, it is not subject to such large and sudden variations in temperature. Sweating is also objectionable with certain cargoes, notably fruit, grain, or flour; in some cases, before loading such cargoes, all iron work below the deck is covered with canvas.

A **wood deck** has several disadvantages; when the timber is inferior or not thoroughly seasoned, it is liable to rapid **decay**; and it decays readily where exposed to heat and moisture, a tendency constantly observed

in the planks adjacent to the boiler casings and in those under deck steam pipes. It is affected by the weather; it **shrinks and expands** with alternations of dry and wet, a circumstance which, of course, has a prejudicial effect on the **caulking** and watertightness. For the first two or three years, the caulking of a wood deck may require attention; afterwards, if the deck is well laid and the timber good, and if the beam surface on which it is laid is well tied and perfectly rigid, it may practically never require recaulking. With inferior timber and workmanship, constant attention may be necessary to guard against leakiness and consequent damage to cargo.

The **duration of a wood deck** depends on circumstances; it may be limited either by the occurrence of general decay or by loss of substance through wear and tear. In a sailing-ship making long voyages, and whose deck is, therefore, little exposed to the wear and tear incidental to loading and discharging operations, a 4-inch yellow-pine deck of good quality may last 20 years or more. It will then probably be reduced to a thickness of about 3 inches, in which case Lloyd's rules would require its renewal (Art. 346). In ordinary cargo steamers, the deck is always plated, for as in these the wear and tear and decaying influences are severe, the duration of a wood deck would be short. The above refers more particularly to pine decks; a teak deck is most durable, both as regards wear and tear and freedom from decay.

The **duration of a plated deck** is only limited by corrosion; it does not decay, and its soundness and watertightness are permanent and assured. The rate of corrosion depends on circumstances; if care be observed to keep it well covered both above and below, with a good adhesive protective coating (see Art. 461), it will endure like other parts of the hull. An upper coating, however, requires constant renewal, for owing to the deck traffic, the wash of sea water, and exposure to heat and cold, it quickly disappears or loses its protective qualities. On this account, it is usual not to provide against corrosion at all, which, of course, when quite unchecked may be very rapid, especially in hot climates, where the intense heat of the sun and wettings from sea water greatly intensify the ordinarily slow chemical action of corrosion.

Art. 164. Steel and iron deck plating differ in their manner and **rate of corrosion.** The former sometimes becomes curiously pitted, the surface becoming irregularly covered with small contiguous cavities, often large and deep, like finger marks in dough. It also wastes uniformly by surface scale. Iron does not often waste by pitting; it does by surface scale, but often in an irregular, mottled fashion, due to local differences in its composition. Unlike steel, iron plates are of variable quality, and are not homogeneous. They are often laminated, *i.e.* they may be made up, more or less, of non-coherent layers, and when these break out on the surface, moisture, entering between, causes internal corrosion, with the result that the layers rise, blister-like, burst away, and expose ragged, sharp edges. Nevertheless, in its non-susceptibility to corrosion, a weather deck of iron is superior to one of steel, and, accordingly, it is now common, in steel vessels, to use iron for this part, increasing, of course, the thickness proportionately with the lesser strength. The greater thickness of an iron deck is an advantage in itself, for it provides a larger margin against corrosion; and, owing to the greater stiffness of the plating, conduces to a fairer surface, and, therefore, from a structural point of view, to a more efficient deck.

Art. 165. Steel and iron deck plating are sometimes chequered, for the sake of the foothold afforded by the projecting ribs. **Chequered deck**

plating is advantageous, however, not perhaps so much on this account—for ordinary plating, when roughened by corrosion, is not slippery—as owing to the circumstance that it affords an excellent surface for preservative coatings. If well covered in the first instance (with black varnish or tar and cement, Art. 468), each little diamond-shaped hollow holds its own covering and is protected from attrition by the projecting chequer ribs. The tops of the ribs offer a small surface, and are kept bright and free from rust by the foot traffic. It is a well-remarked circumstance that a deck, whether of steel or iron, corrodes very little where exposed to the polishing effect of foot traffic; in passage ways between or alongside hatchways, for instance, the plating where trodden upon is usually smooth and clean, while elsewhere it is rough and so much reduced by corrosion as to occupy a lower level.

Art. 166. The deck-stringer plates are connected to the shell by the **gunwale bars.** On the upper deck there is only one, but on those below, two, a continuous one within the frames, and another in short lengths between them, termed "*shell lugs*," "*stringer lugs*," or "*chocks*" (Fig. 1, Plate 19, and Plate 105). Formerly, the upper-deck gunwale bar was sometimes placed below the stringer plate, but this is objectionable, for owing to the incidence of the frames, the heel of the bar instead of its toes must be caulked, and in riveting it there is difficulty in hammering the surfaces together. At one period it was the custom, in the case of awning decks and deck erections, to round the gunwale, as shown in Fig. 8, Plate 12. Beam knees are then dispensed with, and there is no gunwale bar, only a light marginal angle for the wood deck. This construction is now seldom adopted. On lower decks, the continuous gunwale bar is fitted to make good the weakening effect of the notches in the stringer plate, for if not reinforced, the local reduction in sectional area and the sharp corners of the notches would cause concentration of stress, and form starting points for fracture (Fig. 1, Plate 19, and Fig. 15, Plate 89). In some of the earlier iron vessels the lower-deck stringer was not connected to the shell, and there was only one continuous gunwale bar (sometimes worked in conjunction with a narrow vertical strip of plating fitted within the frames, termed a "spirketing plate"); the union of the deck to the side of the hull was then only that due to the beam-knee rivets and a single rivet through the continuous bar at each reverse frame, and it was found to be insufficient, for the beam-knee rivets readily loosened. The system of notching the stringer plate and connecting it to the shell at once increased the rivet connection by about 50 per cent.

The vertical flange of the continuous **lower-deck gunwale bar takes one rivet through each reverse frame** (A, Fig. 1, Plate 19). This rivet would be better omitted were it not for the circumstance of corrosion; for if the two flanges merely touched and were not bound together, rust would accumulate between, waste them locally, and burst them asunder (see Art. 466). As it occurs only at each frame, it weakens the bar just at a place where the longitudinal strength of the structure is already largely reduced, by the transverse line of rivets connecting the shell to the frame and the stringer plate to the beam, and also by the notch cut in the stringer plate. It is of little use structurally, for the union of the deck to the side, as provided by the numerous rivets of the beam knees and stringer lugs, is already ample. Its presence involves additional workmanship, for the gunwale bar requires to be carefully fitted and bevelled, so that its vertical flange may lie in contact with each reverse frame. In practice, proper contact is not always secured; the reverse frames near the bow and stern are seldom quite fair either in bevelling or position, and, to conform with

them, the gunwale bar must be fashioned with similar irregularities (Fig. 9, Plate 80). Deficiencies in contact are usually made good by introducing small liners, or by locally distorting the two flanges with the riveting hammers, in which case only the toe of the gunwale bar is brought home to the reverse frame. On the upper deck, under deck erections, this one-rivet connection is now usually avoided, the reverse frames being cut short below the deck; in which case the gunwale bar need not be bevelled, and, owing to the smaller notch in the stringer, a longer and more efficient shell chock may be secured. It may also be dispensed with, when the frames are of bulb-angle section (Fig. 1, Plate 19), if not, special lugs must be fitted (as in Fig. 8, Plate 9). In the case of frames of Z or channel section it is also very commonly dispensed with, in which case it is well to leave a $\frac{1}{2}$-inch space between the inner flange of the frame and the gunwale bar, which, being filled with cement, prevents the accumulation of rust.

The **gunwale bar** of the upper deck is of heavier **scantlings** than those below, for it serves as a bond of union between the important sheer strake and deck stringer (Plate 4). In very large vessels, to secure a sufficiently extensive and rigid union, a supplementary bar is fitted below in short lengths between the frames (the rules of the Bureau Veritas specify this for large vessels). The gunwale bars of all other decks, both the continuous and intercostal, are of the same scantlings, being rather smaller than the upper deck one; the latter, however, where the frames pierce the stringer under deck erections, is treated as a lower one. The upper deck of a spar or awning-deck vessel is lighter in all its parts than that of a full-scantlinged vessel, its gunwale bar being of the lesser scantlings suitable for lower decks. The gunwale bar of a poop, bridge, or forecastle deck, like all other parts of these erections, is of small scantlings, its sectional area being about 50 per cent. less than that of the upper-deck bar below. The continuity of the upper-deck gunwale bar, where longitudinal strength is important, should be carefully maintained. Its bosom or joint pieces should not have a smaller sectional area than its own, and the shearing strength of the rivets should not be less than the tensile strength of the bar (see Art. 280). Where it meets the end bulkheads of 'midship deck erections, it should run through, so as to scarph properly with the continuous bar within; a good and simple method of arranging this part is shown in Figs. 14 and 15, Plate 15.

Art. 167. Lloyd's rules require the sheer strake to extend above the upper-deck gunwale bar (except in the case of awning decks), for then the stiffening effect it receives from it is better distributed, and there is room above the bar to affix properly the bulwark, rigging chain-plates, etc. The **end joints of the sheer strake** should be considered in their relation to the gunwale bar. With the now almost universal **overlap joint**, a tapered liner is usually fitted behind the gunwale bar so as to fill the vacancy occurring at the forward edge of the lap (see Fig. 12, Plate 15). Sometimes, however, to avoid these, the underlapping plate of the sheer strake is slotted in way of the gunwale bar (see Figs. 10 and 11). **Butted joints** are practically only adopted in large vessels, where the superior strength of double straps is required. Formerly, when all joints were butted, the straps of the sheer strake were always placed, like the others, inside; for although the outside position is advantageous in that it avoids all interference with the gunwale bar, there existed a marked prejudice against it, on the score of appearance. An inside strap may be fitted in one length (Figs. 1, 2, 3, and 6), or in two (Figs. 8 and 9). The former is the better. When so fitted, the gunwale bar must be linered or joggled; the liners may either be fitted in long, parallel lengths between

the straps, or in short, tapered pieces before and abaft it. A long liner is objectionable, because it is heavy and involves three-ply riveting and extra caulking. The short liner minimizes these disadvantages. The joggled method is objectionable, for the sharp bends in the bar and the local heating and smithing reduces its strength. Also, as the bar is usually put in place before the sheer strake (to secure a fair side, see Art. 518), a close fit at the straps and good workmanship is not so assured.

The more usual way is to fit the straps in two, one above and one below the deck (Figs. 8 and 9, Plate 15). The upper strap, to be efficient, must not be too short vertically Lloyd's rules require it to take two horizontal rows of rivets above the gunwale bar, and, accordingly, the height of the sheer strake above the deck must be such as to satisfy this requirement. As the strap must cover the entire joint, its upper portion must overlap the vertical flange of the gunwale bar, for which purpose it may either be joggled or a flush surface secured with a liner. When the joggling is carefully done, so as to secure perfect contact, it is the better method, for it avoids three-ply riveting. As soundness in the riveting of the sheer-strake joints is particularly important, three-ply riveting should be avoided, for it usually implies less cylindrical holes, and, with hand riveting, a chance of unsound rivets; if, however, the fairness of the holes is assured by drilling or rimering, these disadvantages disappear. When a liner is fitted in this way, behind a buttstrap or gunwale bar, it must not be of inferior *liner iron* (see Art. 527); for when so situated it is really a structural part, and is liable to the same stresses as the strap itself. Care must be taken to secure watertightness where the strap overlaps the gunwale bar. It will be observed that, while the sides and upper edge of the strap can be caulked, its lower edge cannot; so that should water pass up behind, it might find access into the hold by the upper edge of the gunwale bar (which cannot be properly caulked before fitting the strap, owing to the absence of rivets), or by the rivet shanks should they not absolutely fill their holes. To ensure watertightness in such a case a stopwater of soft packing must be placed behind the gunwale bar (Art. 326).

Art. 168. With a wood upper deck, there is usually a **gutter waterway** at the gunwale (Plates 101 and 107), so that deck drainage water may lodge therein until it escapes by the scuppers; in its absence, the marginal planks of the deck would always be damp, often with dirty water, tending to their decay and general uncleanliness. Of course, when the sheer strake does not project above the deck, as may be the case with an awning-deck erection (Fig. 7, Plate 59), a gutter waterway is not so necessary, for all water at once flows overboard; but as it would trickle down the vessel's sides, it might be very objectionable, for it might enter the cabin side-lights and render foul and unsightly the topsides. Gutter waterways vary in breadth from 6 to 24 inches; they are made simply by fitting an angle bar on the stringer plate parallel to the gunwale; this forms the margin of the wood deck, the stringer plate beyond forming the bottom of the gutter. They are usually lined with cement, for the double purpose of protecting the stringer plate against corrosion and securing a smooth and cleanly gutter. Before laying the cement the watertightness of the gunwale bar, etc., should be tested with water. A gutter is also advantageous in that the bulwark stays and other fittings may be riveted securely to the stringer instead of being bolted to the wood deck. The angle bar forming its inner margin should be of substantial thickness; for it is specially liable to corrosion, and if the bulwark stays are riveted to its vertical flange (Fig. 4), any outward bursting effect on the bulwark, such as may occur when a large volume of water gets on deck, may strain it away from the marginal

deck plank, start the caulking and cause leakiness (Art. 359). Care must be taken to secure watertightness in the deck at the ends of the gutter waterway, where it abuts against the end bulkhead of the poop, bridge, or forecastle. The ends of the gutter bar require to be smithed at these places, and the work is sometimes badly done, with imperfect contact at the welded and joggled corners.

In passenger vessels, gutter waterways are sometimes provided on all decks (Plate 107). In the case of flying deck erections, such as promenade and shade decks, which are supported at the sides by an open rail, they prevent promiscuous droppings of rain or wash-deck water. Here they may be quite small, being often formed by a channel bar, which, for these light decks, may serve the double purpose of stringer and gunwale bar (Fig. 5, Plate 76). Excepting passenger vessels, gutters are not usually provided on lower decks; they are useful here for collecting drainage, leakage, or wash-deck water, until it finds its way below by the scuppers—provided, of course, on all decks (see Art. 437).

Between each pair of frames, at the sides of decks other than weather decks, there is a natural trough, at one or both ends of which there is an aperture in the stringer (Fig. 1, Plate 19). The troughs are filled with cement, usually quite full, so as to secure perfect watertightness. In the case of lower decks, it is sometimes preferred not to block up the aforesaid apertures, but to retain them as a means of ventilating the hold space below. When passengers are carried above, they must, of course, be filled, so that foul or ill-smelling air from the cargo holds may not ascend and pervade the living space. When apertures are left it is well to arrange them so that they may be closed when desired. This may be done by placing in the stringer notch, when laying the cement, a large tapered pin, which, being withdrawn when the cement is set, leaves a well-formed hole, readily plugged at any time.

When a **wood deck** adjoins an engine or **boiler casing**, the plank in contact therewith **shrinks with the heat**, the caulking becomes defective, and the timber, subject to heat and moisture, readily decays. To avoid this it is now common to substitute for this marginal plank a gutter, fill it flush with cement, and, perhaps, tile the upper surface (Fig. 21, Plate 15). For the same purpose, **cemented gutters** are often fitted **under deck steam pipes.** A channel bar is particularly suitable for this purpose.

Art. 169. The **upper-deck scuppers** should be considered in connection with the gunwale bar (Figs. 16 to 20, Plate 15). Their purpose, of course, is to drain small quantities of water from the deck, egress for large volumes being provided by large freeing ports placed higher up in the bulwark (Fig. 3, Plate 59). To drain all water from the deck they must be level therewith, or with the bottom of the gutter. They are usually formed simply by cutting a hole through the gunwale bar and sheer strake, so that water may pass at once over the side. In passenger vessels, however, where it would be objectionable to have water trickling down the topsides, over or near the cabin sidelights, it is conveyed from the bottom of the gutter by a pipe, which debouches through the ship's side below the lights (see Fig. 22, Plate 15). With the first type of scupper care should be taken to maintain the strength of the gunwale bar where cut away by the hole. Formerly it was usual to increase the depth of the vertical flange at the scupper, smithing it so that it might form a neat frame around the hole (see Fig. 18). By the plan now generally adopted, advantage is taken of the discontinuity necessarily prevailing at each joint of the gunwale bar; instead of placing the joint piece in the usual way, in the bosom of the bar,

it is fitted below the stringer, the ends of the gunwale bar being kept a few inches apart, so that the scupper hole may be cut in the sheer strake between them (see Fig. 19). In order that the joint piece may scarph sufficiently with the disunited ends of the gunwale bar, it should be more than a frame space in length, and, to allow of this, one or two frames must be cut short (see Fig. 20). This, however, is not often done. It is not usually necessary to reinforce the sheer strake where pierced by the scupper; for the material cut away by so small a hole does not exceed that removed at each of the numerous lines of frame rivets. It is important, however, that the scupper hole should not be placed over a frame. In order that water, issuing from the scupper hole, may properly eject itself and not trickle down the ship's side, it is common to provide a sill or lip, formed by a casting or small angle lug (Fig. 16). Sometimes, to avoid cutting the gunwale bar, a modified form of scupper pipe is employed, in the form of a small cast-iron or dished-steel drain, leading from a hole in the stringer plate to one in the vessel's side immediately below the same (Fig. 17). A casting, if adopted, is very compact, and is, therefore, little exposed to injury.

CHAPTER XIV.

Art. 170. Few vessels are seaworthy when light, *i.e.* when carrying neither cargo nor ballast. Through lack of stability they might be in danger of capsizing, and although, if very broad, they might be sufficiently stable, they would not be weatherly or navigable; floating like a bladder, with no grip of the water, but with a large surface exposed to the wind and waves, it would not be possible, in heavy weather, to keep a steady course to windward. Accordingly, when a vessel requires to move from port to port without cargo, or with too little, or with one of a very light nature, the necessary immersion and stability must be secured by ballast. Until about the year 1855, stone, rubble, or sand ballast was alone employed; it is still, in sailing-ships, but in nearly all steamers provision is made for carrying **water ballast**, either in double-bottom tanks or *deep tanks*, the latter being a small portion of the hold partitioned off and specially constructed to hold water.

The use of water ballast originated in the coal trade between London and Newcastle.[1] At one time this was entirely conducted by small sailing-ships, which, for each return voyage, loaded and discharged stone ballast. The cost of the ballast and the work and time lost in loading and discharging it was a serious inconvenience. Water ballast costs nothing; it loads itself, and may be discharged rapidly by the pumps. Having steam pumping power, steamers are specially suited for water ballast. When first adopted in some of the early ships, the tanks were emptied when the tide left the vessel high and dry, by withdrawing a plug from the bottom. In the case of the early steam colliers the adoption of water ballast answered so well in promoting economy and despatch in port that, although in other respects a more costly means of conveyance, they soon took the trade from the slow-going sailers.

When employed as ballast, water must be confined; were it free to move from side to side, it would cause the vessel to heel over and be a positive danger instead of a security. **When first used** it appears to have been confined by the crude means of watertight bags, which, of course, possessed the merit of occupying little space when empty. About the year 1854 numerous independent shallow tanks were employed, built to lie on the tops of the floors, and connected by pipes for filling and emptying purposes. Subsequently it was realized that if the vessel were built with a double bottom, the intermediate space would serve as a ballast tank, the strength of the bottom would be increased, and safety secured in case of damage to the outer shell. A double bottom has the further advantage of reducing the tonnage;[2] but it also reduces the capacity of the holds as

[1] See the late Mr. Martell's paper, "*On water ballast*," *Trans. Institution of Naval Architects*, 1877.

[2] When first introduced on the McIntyre system, the double bottom did not secure this advantage, for in making the necessary measurements for tonnage the Board of Trade officials did not depart from the strict letter of their rules, which required that the depth of hold should be measured from the tops of the floors.

regards measurement cargoes. Compared with stone ballast, water is light, and so occupies more space; but, of course, the greater part of that appropriated by it, is useless bilge space. Stone ballast also takes up space; sometimes, therefore, in sailing-ships, to secure more hold room for light cargoes, some of it is stowed under the ceiling, between the floors; but this, of course, is an objectionable expedient, for should any of the stones move with the rolling of the ship, the cement would be rapidly worn away, and then the exposed rivet heads would disappear, to the danger of the ship.

Art. 171. A double bottom may prove very useful in limiting the disastrous consequences of striking a sunken rock, or of running aground; for although the outer one may be ripped open, the inner, remaining intact, may save the ship, or, by retarding the inrush of water, prevent sudden foundering and loss of life. Again, in case of minor damage to the bottom, should leakage water enter the ballast tanks, it would do no harm, but, if it entered the holds, it might (though perhaps ultimately controlled by the pumps) damage valuable cargo. Numerous cases are on record wherein disasters, great and small, have been averted by the presence of a double bottom.

The degree of **safety conferred by a double bottom** depends very much, of course, on the completeness of the duplication; for the inner one or tank top does not always extend all fore and aft, but may be confined to the forward or after hold; it may not cover the lower part of the bilge (Fig. 14, Plate 17), and in many cases small discontinuities, "*well spaces*" as they are termed, are introduced for pumping purposes (see Arts. 417 and 420). If regarded only in its aspect as a security against chance rupture of the outer bottom, such incompleteness might well be thought fatuous; in ordinary merchant vessels, however, a double bottom is not fitted for this purpose, but as a receptacle for water ballast. The safety it confers may be regarded as an adventitious benefit, hence this feature is not always specially studied. The contingency of the outer skin being seriously injured through grounding, striking sunken rocks or submerged wreckage, is remote; and, moreover, safety would not always be assured, for the injury might be so serious as to involve both bottoms, or it might be inflicted well up on the bilge where there is only one. **In warships the double bottom** is carefully designed to form a complete inner skin. Here its primary purpose is to give security against damage to the shell; its efficiency is, therefore, particularly studied; in place of terminating below the bilge, as in merchant vessels, it is carried up above it, and thence the duplication is extended above the load line by longitudinal bulkheads, the greater distance of which from the side gives a surer protection against the incident of torpedo explosion or ramming (see Plate 113). In carrying water ballast, the double bottom is useful as a means of adjusting the draught and trim, so that the proper immersion of the side armour or protective deck may be maintained irrespective of the consumption of coal or damage sustained in action.

Whatever the design of the double bottom (whether complete or otherwise), it does, of course, greatly reduce the chance of disaster through **injury of the outer skin**; and although such a contingency may be a remote one, not warranting any structural modifications that would reduce the vessel's efficiency as a cargo carrier or greatly increase her first cost, still, it is evident that it should receive consideration in the design. In practice this is sometimes given and sometimes not; in large modern passenger vessels, where safety to life is the first consideration, care and forethought are exercised to render the ship as secure against foundering as practicable, by a complete watertight double bottom and by numerous watertight bulkheads. It might appear that when a heavily laden vessel

strikes a sunken rock, the inner bottom, situated within 3 or 4 feet of the outer one, and connected thereto by stiff floor plates, would also inevitably suffer; but this is not usually the case, for it is common to find that while the shell and lower parts of the floors and longitudinals are torn and crushed, the inner bottom has remained intact and practically watertight. A case of the kind is shown in Fig. 6, Plate 18, which represents the damage actually suffered by a warship through running upon a reef.[1] It should be observed that when a vessel's bottom strikes a reef, not all her weight presses thereon, but just sufficient to lift her by a few feet, until she is brought up; the penetration of the rocks may, therefore, be similarly small; and if, having an inner skin, the water does not enter the holds, there is a good chance of salvage.

Art. 172. There are two types of **deep tank** (Fig. 6, Plate 20, and Plate 110); those placed amidships for the purpose of sinking the vessel bodily in the water, so that her weatherly and navigable qualities may be maintained at sea; and **trimming tanks**, placed at the bow or stern, termed respectively the "*fore-peak*" and "*after-peak*" tank, which serve the same purpose, but also permit of the trim being adjusted, so as to secure an even keel should the cargo stowage or consumption of coal during the voyage cause an undesirable departure therefrom, or to increase the immersion of the propeller should the vessel be light, or secure, by an even trim, a smaller mean draught when entering shallow harbours or docks. Nearly all modern steamers have an after-peak tank, because ballast at the stern is particularly useful in securing immersion of the propeller when light; not so many have a fore-peak tank. 'Midship deep tanks are sometimes fitted as a substitute for a double bottom, but more usually they are fitted in conjunction with them, the deep tank over the double bottom.

The water ballast contained in the double bottom only increases the vessel's immersion by about 2 feet. In a large, modern, cargo vessel it represents only about 15 per cent. of a full load of cargo (in smaller it may exceed 20 per cent.), the **ballast draught**, with bunkers full, being about half the **load draught.** It is evident, therefore, that when floating so lightly on the water, a vessel's weatherly and navigable qualities in heavy weather must be very poor. The propeller, for instance, being only partially submerged, has very inferior driving power (when a vessel in ballast trim encounters heavy weather, she may take more than twice as long on a voyage as when fully loaded), and the shocks incurred due to its rising out of the water, racing violently, and then being suddenly brought up by immersion in the waves, are very apt to cause fracture of the blades or of the tail-shaft. To immerse it merely by trimming the vessel by the stern, might so much raise the fore-foot as to make the vessel still less navigable against head seas, and perhaps result in damage to the fore-foot (Art. 108). In view of the above, when a large vessel is about to make a long voyage without cargo, it is usual to secure deeper immersion by loading supplementary stone ballast.[2] In a perfectly light vessel of the modern broad-beamed type, the stiffening effect of ballast, which in the early vessels was the sole reason for carrying it, is not required; with the double bottom full, the stiffness or stability (as measured by the meta-centric height) is usually so excessive as to make her very uneasy at sea, she may roll in so violent and spasmodic a fashion as to strain the structure and make life almost intolerable to those on

[1] H.M.S. *Howe.* See *Engineering*, September 8, 1893.

[2] It has often been urged that vessels should not be allowed to proceed to sea unless well immersed, the imperfect navigability and bad weatherly qualities due to insufficient immersion being a source of danger to both life and property. A Select Committee, known as the "Light Load-line Committee," was appointed by the House of Lords in 1902 to consider this matter, but, after receiving evidence, they concluded that statutory regulations were not called for, there having been no serious loss of life on vessels in ballast.

board; straining from this cause is often observed in the connection of the side frames to the margin plate of the double bottom. With a view to remedying excessive stiffness, it is common, when supplementary ballast (or reserve coal) is carried, to place it in the upper 'tween decks; and in some cases, when at sea, the upper deck is flooded with water, between the bulwarks, all holes in the latter being stopped up.

Deep tanks are better than a double bottom in that the centre of gravity of the water they contain is fairly high, much the same as that of ordinary cargo. They occupy valuable hold space, but large watertight hatchways are provided, so that they may also be available for cargo. When thus adapted, the tank is included in the tonnage measurement, otherwise it may not be. In order that it may be used for all kinds of cargoes, a deep tank should be long; as now adopted, they are often so large as to contain the same weight of water ballast as the double bottom itself, increasing the vessel's immersion by another 2 feet or so, and when there are two such tanks, as is now fairly common, the total weight of water ballast, including the peaks and double bottom, may exceed 40 per cent. of a full dead weight cargo (including bunker coal), thus securing good weatherly and navigable qualities in light trim. A 'midship deep tank is usually placed immediately abaft the machinery space (Plate 110), or if there are two, one before and one abaft it, as in Fig. 6, Plate 20. Otherwise they may be placed as in Fig. 7, which disposition has the advantage of not causing an increase in the sagging stresses which occur when a vessel is in ballast trim with bunkers full. A single, large, deep tank, forward of a 'midship machinery space, may have the disadvantage of causing the vessel to trim by the head when light. The tank top is usually formed by the lower or second deck; when extended to the upper deck of a large vessel, it becomes so deep as to cause excessive fluid pressure on the containing walls, necessitating double-riveted seams and special stiffening. When just in front of the machinery space, it is usually arranged to serve also as a reserve coal bunker, special watertight doors being provided in the bulkhead separating it from the stokehold.

Art. 173. To raise the centre of gravity of the ballast, and at the same time increase the quantity carried, **ballast tanks** have sometimes been fitted **on the upper deck**, having a capacity about one-third that of the double bottom. With these and the double bottom full, the centre of gravity of the ballast, instead of being about 2 feet above the top of the keel, is raised to about one-quarter of the vessel's depth. The deck tanks are constructed by fitting longitudinal girders about 3 feet deep on the top of the quarter-deck, and plating them over. In steadying the ship and securing good immersion of the propeller, this arrangement has proved satisfactory. As already noticed, to steady a light ship in moderate weather, free water is sometimes carried on deck. In some recent vessels a portion of the upper 'tween-deck space before and abaft the machinery space is partitioned off to form **'tween-deck ballast tanks.** In way of each tank a centre-line wash bulkhead is fitted from deck to deck; the beams below are strengthened, and an intercostal girder fitted below the deck on either side, supported by pillars; the central hatchway is trunked through the tank, and special watertight side hatchways provided for the stowage of cargo in the tank.

For a similar purpose a few single-deck cargo vessels are constructed with double sides, about $2\frac{1}{2}$ feet apart below the upper deck, for about half the vessel's length amidships[1] (see Plate 112). The **side tanks,** so

[1] *MacGlashan's Patent*, as adopted in the s.s. *Mancunia*, etc. Registered dimensions, length, 345 feet; breadth, 51 feet; depth, 24·4 feet.

formed, have a capacity about three-quarters that of the double bottom, the latter, of course, being retained. The fact of the water ballast in the side tanks being so remote from the vessel's centre-line, is advantageous in making her easy in a sea-way, her period of oscillation, due to her greater transverse moment of inertia, being longer and not so likely to synchronise with that of the waves ordinarily encountered (see Art. 354). The double sides are united by cellular framework, and as they confer great strength on the hull, they permit, in a large vessel, of the complete suppression of a second deck. As cargo may be stowed against the inner walls, there is comparatively little loss of hold space, and the double sides give some security against foundering by collision.

In some vessels the **shaft tunnel** is employed **as a supplementary ballast tank,** thus securing, on occasion, greater immersion at the after end, with a comparatively small increase in stiffness.

Art. 174. Sailing ships are seldom provided with a **double bottom,** for several reasons. The saving of time in port (as a rule, they are only in port about twice a year) is a comparatively small matter in a slow-going sailing ship; and a double bottom involves special pumping arrangements, and increases the first cost. But, moreover, the water ballast contained in a double bottom is insufficient, and is too low down; to immerse a light ship sufficiently and make her perfectly safe for a sea voyage, supplementary stone ballast would still be necessary. To avoid this necessity, some large modern sailing-ships, are provided, in addition to a double bottom, with large **'midship deep tanks,** carrying as much water again as the double bottom; they are subdivided horizontally and vertically, and are arranged to carry cargo when required. A double bottom has the disadvantage that, when the vessel is loaded to her deepest draught, with the holds quite full of homogeneous dead-weight cargo, the entire mass is necessarily some 2 feet higher up than it would be were there no double bottom. In a crank, narrow ship this may result in insufficient stability, to correct which the double bottom cannot, of course, be filled, the vessel being already at her statutory load line. When double bottoms were first introduced, the steamers of the period were deep and narrow, and as they loaded deeply, they had naturally but a small margin of stability; the introduction of a double bottom, therefore, made matters worse, for, by elevating the cargo, it so seriously reduced the small margin of stability that many serious losses occurred.[1] In modern steamers, owing to their large beam, this danger no longer exists (on the contrary, they are usually too stiff), but in narrower sailing-ships it does, and, as they are subject to the heeling effect of the wind, they require a larger margin of stability.

Art. 175. Although, in its adaptability to carry cargo, a **deep tank** is better than a double bottom, it has none of the safety-giving features of the latter, and, instead of being a source of strength, it is apt to be one of weakness. As regards longitudinal stress, the fact of so much weight being concentrated at one point in a light ship, may considerably accentuate ordinary hogging and sagging stresses. Then the structure of the tank itself may suffer **local stresses,** statical and dynamical, due to the pressure and movement of the contained water. As water pressure is proportional to the depth of the liquid, the containing walls of a deep tank may be liable to a bursting pressure of great magnitude; they must, therefore, be very strongly constructed, for, not being intimately connected like the tank top and shell plating of a double bottom, they must be self-supporting (see Plates 24 and 25). The bursting pressure to which they are exposed is not, of

[1] See Martell's paper "*On the causes of unseaworthiness in merchant steamers*," *Trans. Institution of Naval Architects*, 1880.

course, merely that due to the depth of the contained water, for, owing to the vertical movement of the ship, this may be greatly augmented. Further, in the contingency of a partially filled tank, the water, being free and unrestrained, may dash about with such violence that its **concussive effects** on the containing walls may strain the various riveted connections. The dangerous circumstance of a partially filled tank not infrequently occurs; it may be through negligence on the part of those whose duty it is to fill it, concluding that it is full when it is not, or it may happen through the ignorance or carelessness of those in charge, who, to improve the trim or weatherly qualities of the ship, may cause it to be filled or emptied at sea, during heavy weather, when the vessel is rolling and pitching. To provide against violent movement of free water, deep tanks are furnished with a central fore-and-aft bulkhead, sometimes termed a "*wash bulkhead.*" This is not usually made watertight, but, as it reduces by half both the volume of the moving water and the transverse distance through which it may travel, the energy or damaging effect which it may acquire becomes comparatively unimportant. In the case of the peak tanks a wash bulkhead is also required (it may be very necessary here, because, as these tanks are often used for drinking water, they may not often be quite full); as they are narrow at the lower part, however, and as it is only the surface water that acquires violent motion, the bulkhead need only be fitted at the upper part, extending a few feet down from the tank top (Fig. 9, Plate 10, and Plate 109). Ordinary cargo does not take contact with the ship's plating, whereas water ballast does, and it tends, therefore, to force it away from the frames and strain the connecting rivets; for this reason it is found necessary, in the case of deep and peak tanks, to space the rivets connecting the frames to the shell 6 diameters apart in place of the 7 diameters elsewhere found sufficient.

Art. 176. When **double bottoms** were first adopted in merchant vessels, the simplest **method of construction**, involving the least departure from the usual structural design, was followed. The ordinary floors were retained, and the side keelsons increased in height and in number, so as to form fore-and-aft bearers (or "*girders*," as they are usually termed) for the tank top (Fig. 1, Plate 16, and Plate 103). The latter must be raised well above the floors. To provide space for a sufficient weight of water, and access for a man to pass conveniently over the tops of the floors, there should be at least 18 inches between them and the tank top, and if manholes are punched in the girders, considerably more than 18 inches. With minor modifications, the above arrangement is still sometimes adopted, and is generally known as a "**McIntyre tank.**" It is limited chiefly to small vessels, in which there may only be a partial double bottom; for, being built as an addition to the ordinary bottom framework, it is here simple and convenient. It also has the advantage of greater accessibility; especially in small vessels, where, in a cellular double bottom of the same depth, the manholes in the floors would necessarily be small. Further, in case of damage to the bottom, the repair work is usually less extensive and costly.

The introduction of a McIntyre tank strengthens the vessel's bottom; this will be evident from a comparison of Plates 103 and 101, which represent a vessel so constructed and one framed in the ordinary way. The former is stronger longitudinally, for there are more side keelsons, each one being a deep girder, having a wide upper flange in the tank-top plating. It is also stronger transversely, because each floor is held down by the numerous girders, and, instead of having a small neck at the bilge, has a rigid bracket attachment, which reduces its length and increases its strength and stiffness under deflecting forces. Although not essential in

a double bottom of this type, there is usually an intercostal connection between the centre girder and the keel (and sometimes one on either side), which, by uniting the tank top and shell plating, greatly increases the strength of the bottom at this part; the same effect is, of course, secured at each margin plate. In some large modern vessels, having a double bottom on this system, the vertical keel is a continuous plate, the floors being severed on either side and connected thereto by large vertical brackets, as shown in Fig. 4, Plate 103. In the absence of fore-and-aft vertical plates directly connecting the inner and outer bottoms, the latter parts could not co-operate efficiently in resisting upheaving forces, for they would not form the top and bottom flanges of a deep girder; as noticed, Art. 61, the transverse floors do not form a substitute for such connection, for, being mere parallel connecting links, liable to trip, they are incapable of transmitting fore-and-aft stresses from the one part to the other. For the same reason, when the floors are exposed to transverse bending stresses, the tank-top plating can give little or no assistance, because the fore-and-aft girders do not constitute a rigid transverse web. The girders, of course, are most efficient in holding down individual floors, or groups of floors, but they can give little assistance against widely applied upheaving pressures (Art. 24). Much of their efficiency as independent girders, moreover, is usually sacrificed by the meagreness of their end joints, these, as a rule, being only single riveted, and in some cases they may be weakened by large manholes. It thus appears that, although a double bottom on this principle confers additional strength, the design is *not* an efficient one; that is to say, it is not such as to secure from the structural material employed its fullest capabilities in the matter of strength.

Art. 177. It should be observed that in merchant vessels a double bottom is not usually fitted with the object of strengthening the bottom, for in vessels having none this is strong enough. Nevertheless, as the deforming forces, local and otherwise, to which the bottom is liable, may at times be exceptionally severe, or even irresistible, a margin of strength, larger than what might suffice, whether it be obtained designedly or adventitiously, is always desirable; and, accordingly, if, by a modification in the structural arrangement, not interfering with other qualities, a greater degree of strength can be secured, it is well that it should be made. It was with this object that the **cellular type of double bottom** was introduced. It was first adopted in warships, about the year 1866, and in merchant vessels about 1876.[1]

The **structural arrangement of a cellular double bottom** may be described, in a general way, as a McIntyre tank (Fig. 1, Plate 16) in which all the girders are extended down to the shell and all the floors up to the inner bottom (Fig. 2); crossing one another, they form numerous cells, hence the term "*cellular.*" With so much added material, the strength would, of course, be greatly increased, for each longitudinal girder would form practically a deep vertical keel, having a wide top and bottom flange, and each floor a deep transverse one. When so arranged, the entire bottom structure might be regarded as composed of a series of contiguous box girders, longitudinal *and* transverse; each of the former being composed of a strip of inner and outer bottom and a pair of longitudinals,

[1] A description of the cellular double bottom first adopted in warships will be found in Sir E. J. Reed's work on ship-building; and those first adopted in merchant vessels are well described by the late Mr. John, in his paper, "*On cellular construction of merchant ships*," *Trans. Institution of Naval Architects*, 1880. It should be observed that the s.s. *Great Eastern*, built in 1858, had a double bottom on the cellular system, or rathe a complete inner skin; a description of this vessel will be found in Scott Russell's work on shipbuilding.

and each of the latter of the same and a pair of floors (see Figs. 2, 7, and 8). In practice, of course, the above arrangement is not carried out in its entirety, for the weight and strength would be altogether excessive; while still retaining ample strength, about half of the parts are omitted, and many are lightened by large holes (see Figs. 3 and 4).

When thus suppressing some of the too numerous connecting webs (floors and longitudinals), there is a choice between the transverse and the longitudinal; in practice sometimes the former and sometimes the latter are suppressed, and, consequently, there are two **types of cellular double bottom**; the **longitudinal** (Fig. 3, Plate 16), in which a great part of the material is placed fore-and-aft, and the **transverse** (Fig. 4), in which most of it is placed athwartship. When first introduced, the longitudinal arrangement was alone adopted, for at that time to increase the longitudinal strength was thought desirable (see Art. 39). It is still adopted in warships (Fig. 5 and Plate 113), and—in modified form—to a considerable extent in merchant vessels, but the transverse system is now generally preferred; for, while simplifying the constructive work, it affords greater strength against grounding pressures. The relative efficiency of keelsons *versus* floors was noticed in Art. 24, and the principle there noted applies equally here, namely, that as each floor, spanning the distance from bilge to bilge, forms a short girder, it is stronger and more capable than the longitudinals, spanning the greater distance between transverse bulkheads. Accordingly, where strength of bottom against grounding pressures is desired, it is evidently better to retain all the floors.

Art. 178. Notice, in the first place, the structural arrangement of a **cellular double bottom on the longitudinal principle** (see Fig 3, Plate 16, and Plates 88 and 102). Here the longitudinals are placed about 4 feet apart, and, as alternate floors are omitted, they also are 4 feet apart. While omitting alternate floor plates, their frames and reverse angles are retained, to give local stiffness to the shell and inner-bottom plating; as a rule, however, the reverse bars are omitted, the thickness of the tank-top plating being slightly increased (usually by $\frac{1}{20}$ inch) as compensation for the loss of their stiffening effect. The ends of the intermediate frame angles are connected to the vertical keel and margin plate by bracket plates. Formerly, with a view to securing longitudinal strength, the longitudinals were fitted continuously, and the floors in short pieces, or diaphragm plates between them (Fig. 7, Plate 16); but now, except in warships, this is usually reversed, the floors being continuous and the longitudinals in short lengths (Fig. 8), for, while greatly simplifying the constructive work, it increases the strength against grounding pressures. Of course, in every case the centre longitudinal or vertical keel is fitted continuously, the floors being connected thereto by short vertical angles, one in vessels of moderate size (under 24,000 plating numeral), and two in large ones; and similar single connecting angles are fitted at the intersection of each floor and longitudinal. If the floors and longitudinals are regarded as forming merely the connecting webs of numerous conjoined box girders, discontinuities in the strength of either would be unimportant; but, although slender, they really form in themselves deep and capable girders, and, as such, continuity of strength is very desirable; but more particularly in the floors, because, as they form short girders, they suffer greater stress and are more capable in resisting deflecting forces. Of course, when the longitudinals are regarded as fore-and-aft parts, contributing strength to the hull (as a whole) against hogging and sagging stresses, a maintenance of their sectional area, to enable them to

withstand purely tensional stresses, is important. But their duty in this respect is a very minor one, for, when strengthened by the addition of an inner bottom, the lower part of the hull is, in any case, stronger than the upper (see Art. 39). In the early vessels the matter was not looked at in this way; the longitudinals were deemed capable of contributing useful longitudinal strength, and so their continuity was regarded as specially important. The floors, on the other hand, were regarded as minor parts, quite subordinate to the longitudinals, so that while the latter were composed of a continuous solid plate, the former were often arranged on the bracket system (see Fig. 6).

If, as just noticed, the floors are regarded merely as the connecting webs of transverse box girders, their place might be taken by diagonal lattice links (see Fig. 6, Plate 114), but although a lattice formation is perfectly efficient for the web of a girder pure and simple, it is not so for the floor plates of a ship, for it can offer little or no resistance to upward crushing pressures. It is still less suitable for the longitudinals, because these may suffer longitudinal stress, to which diagonal links can give no resistance. In its mechanical characteristics a floor formed of bracket plates (Fig. 6, Plate 16) is identical with one of lattice links; if, in the latter, some of the triangular spaces were filled in, the result would be a **bracket-plate formation.** But a bracket floor is superior in that, being more substantial, it can offer more resistance to grounding stresses, where the upward pressure of the ground and the downward pressure of the contained cargo tend to crush the two bottoms together. The larger and heavier the vessel, the greater are such pressures likely to be, and so, although at one time the bracket system was adopted in large vessels, it is now only deemed applicable to small ones (Lloyd's rules permit of it in vessels under 11,000 plating numeral). An important duty of the bracket plates is to stiffen and hold erect the various longitudinals; in the case of the vertical keel, therefore, which suffers the most severe pressures, each vertical pair is formed of a single plate, which, of course, gives a much better supporting effect (see Fig. 6). And in warships, where this system of construction is still in vogue, all the brackets are formed in this way (see Fig. 5). Although admissible in small vessels, the bracket system of construction, as regards merchant vessels, is practically obsolete, for it gives a less strong bottom than the solid floor arrangement, and involves continuous longitudinals and costly constructive work.

Art. 179. Notice now the general features of a **transversely arranged cellular double bottom** (see Fig. 4, Plate 16, and Plate 106). Here all the floors are retained, and the longitudinals reduced in number; in a tank less than 34 feet wide amidships, only one longitudinal is fitted on either side, if wider, two (Plates 4 and 105). It is hardly proper to describe them as longitudinals, for, being in short lengths between the floors, they are mere intercostal plates, and, moreover, they may not even lie in continuous fore-and-aft lines. Their purpose, of course, is to hold the floor plates erect against the side-bending tendency which plates so deep would readily exhibit, and to form intermediate fore-and-aft connecting webs between the shell and inner bottom. Comparing this type of bottom with the longitudinal one just described, it is simpler to construct because there are only two kinds of parts, the floors and intercostals, which are easily made and readily put together; and, of course, with double the number of powerful transverse floors, the bottom is more capable of withstanding severe grounding pressures. Again, the shell plating, being rigidly supported at intervals of about 2 feet instead of 4, is better able to resist local pressures, so much so

that it may be slightly reduced in thickness[1] (Art. 115). In the longitudinally arranged bottom, there are, of course, intermediate angle frames, but these have not the unyielding qualities of floor plates (Plate 102). As regards longitudinal strength, any little difference between the two systems is small, and, in view of the great accession of strength secured by the double bottom, is usually quite unimportant. On the other hand, the longitudinal arrangement is advantageous in that the tanks are more accessible. In the transverse type, to creep through a series of manholes, in floors so close together as 2 feet, is an awkward matter, for before clear of the one another is encountered. This consideration, however, does not usually carry much weight.

Art. 180. The **floor plates** of a cellular double bottom are always lightened by large **manholes**, or **lightening holes.** If the longitudinals are worked continuously, their sectional area should be maintained, consequently, only such manholes should be provided as are necessary to give access to every part, and they should be so disposed as not to fall opposite one another in the same transverse line; and similarly in the case of the girders of a McIntyre tank, but here manholes are not usually necessary, for there is generally ample space below the girders for a man to pass. Manholes are not often punched in the important vertical keel, except where it may be of extra depth. When the longitudinals are fitted intercostally, as is usual, they may be lightened like the floors, for as they are jointed to the latter, merely by a single angle, the reduction in sectional area does not prejudice their strength (Figs. 4 and 5, Plate 88, and Plate 102). The manholes in the floors do not hurt their efficiency as rigid connecting webs, nor even as independent girders, so long as they are carefully disposed, and are not too large. Nevertheless, whatever holes there may be, must reduce the capabilities of the plates in resisting upward crushing pressures, and in view of this and of the natural tendency to save weight by punching unwarrantably large holes, the classification societies discountenance, generally, the lightening of structural material by holes, and of punching larger ones in the floors than is necessary for convenient accessibility. A small lightening hole is usually punched in the bracket outside the tank margin plate (Plate 106), but as there is here no question of accessibility, it is common to substitute a number of small holes, uniformly distributed, these being better in that they create no distinct line of weakness (Plate 105). In warships, the floors, and all diaphragm-like connecting plates, are pierced with very large lightening holes, for the express purpose of reducing weight; they may leave the plate a mere skeleton, but even so, although less fitted to withstand abnormal crushing pressures, they are still efficient as connecting diaphragms. It might be thought that where lightness only is sought, it could be secured more simply by reducing the thickness of the plates, and leaving them intact; but although the weight or mass of metal might be the same, the plates would be less stiff, and much less enduring against corrosion.

Art. 181. The **framework** of a double bottom is always **increased in strength under the engine**, to give stiffness and solidity against the vibrating and straining effects peculiar to this part. In the longitudinal type of bottom, in which only alternate floors are fitted, they are fitted under the engine on every frame (Plate 88), and in no case is a bracket construction adopted at this part. In the transverse type, in which the floors are on every frame, the necessary increase in strength under the engine is obtained by introducing two or three additional rows of intercostal plates (Plate 104). Also, whatever the type of bottom, the reverse bars on

[1] This is also permissible in a McIntyre tank.

the upper edges of the floors are doubled in the engine and boiler room. In the longitudinal type of bottom, Lloyd's rules require at the **forward end**, for one-fifth the vessel's length, floor plates to be fitted on every frame (Plate 88), to provide against the dynamical stresses peculiar to this region; and in the transverse type, an additional line of intercostals is required, which, being fitted merely to stiffen the shell plating, may be of half height (see Fig. 3, Plate 88). In addition to this, in full vessels all the floors in this region must have double shell angles (Art. 108).

Art. 182. The foregoing describes the cellular double bottom construction generally adopted in merchant vessels, but, of course, modifications, small or large, are often made. In some longitudinally arranged double bottoms, the longitudinal parts are increased, and the transverse reduced, *i.e.* the longitudinals are placed closer together, so that by reducing the area of shell plating lying between them, the intermediate frame angles, otherwise required to support them, may be dispensed with. In others, the transverse elements are increased and the longitudinals reduced; the longitudinals are placed wider apart, and the intermediate frame and reverse angles—not having a floor plate—rendered more efficient by forming them of deep angle, bulb angle, Z, or channel bars, and connecting them to the longitudinals by bracket plates.

If, as in warships, the longitudinals are fitted continuously, their lower angles are sometimes severed in favour of continuous frame angles. By doing this the constructive work is greatly facilitated, for the floors, instead of being in detached pieces, may be erected in one with the frame angles; so that the longitudinals may be dropped down at any time between them. If the frame angles are severed, the inner diaphragm plates of the various floors must first be erected and fixed to the vertical keel, then a longitudinal fitted on their outer ends, and the same operation repeated again and again, the bottom structure growing slowly, piece by piece, out from the keel.

Art. 183. In **warships** the **double bottom construction** is peculiar (see Plate 113). It is lighter throughout than in merchant vessels; for the floor plates and longitudinals are not only thin, but may be 50 or 100 per cent. further apart. The floors are represented by bracket plates, those which are solid being extensively lightened by large holes. The longitudinals are worked continuously, and in these vessels this is very proper, because, owing to their large beam, the breadth from bilge to bilge, or even from keel to bilge, may exceed that between transverse bulkheads —these being both numerous and closely spaced. The design of the brackets is different from that at one time adopted in merchant vessels; each vertical pair is formed of one plate, and they merely grasp *the ends* of the frame and reverse bar. While affording, therefore, good support to the longitudinals, they leave unaided the central portion of the frame angle and reverse bar, and as there are no intermediate angles, and as the floors and longitudinals may be 4 feet apart, it is clear that the shell plating must be much less capable of resisting local grounding pressures than that of merchant vessels. In warships, however, this quality is of minor importance, for heavy cargo is never stowed on the inner bottom, they do not enter shallow tidal harbours or rivers, and, being navigated with exceeding care, they seldom, if ever, touch the ground. Further, there need be little or no margin of strength or massiveness against deterioration, for they are not constantly exposed to the wear and tear of active service, and their up-keep, as regards cleaning and painting, is continuous and thorough. To provide, therefore, as is done in merchant vessels, a large margin of strength, would not be expedient; for, of course, whatever weight of

structural material is saved, permits of an increase in offensive, defensive, and other qualities. In some later, large vessels the free edge of the bracket plates is cut parallel to the other, and flanged, a lightening hole being punched in the plate (see the dotted lines in Plate 113); but while this gives greater strength and stiffness against stresses tending to force up the outer bottom, it localizes the thrusting effect on the inner one, and is more likely to result in damage to this in the event of the outer bottom being injured (Fig. 6, Plate 18).

Apart from the bottom framework, the **structural design of a warship** differs greatly from that of a merchant vessel. The latter are designed to carry all sorts of cargoes, heavy and light, stowed promiscuously, and often carelessly, on the inner bottom or 'tween decks; and they are expected, when so loaded, to endure, year after year, all sorts of weather and it may be an occasional grounding, without signs of straining or of serious deterioration; further, they receive only periodical survey, and are often unfairly treated as regards cleaning and painting. To satisfy these requirements, an ample margin of strength and massiveness is evidently essential. Warships, on the other hand, carry no cargo; they carry heavy weights of armament and coal, but the former, if not incorporated with the structure of the hull, are placed in specially assigned positions, and are definite in amount. The hull is rendered stiff and strong, not merely by side framing, but by numerous plated decks and transverse and longitudinal bulkheads; at mid-depth there is a protective deck of steel plating, 2 or 3 inches thick, which in itself forms an immensely rigid diaphragm, conferring great strength and stiffness on the hull as a whole. The side frames lying between the bulkheads and decks, having, therefore, only the minor duty of stiffening the intermediate areas of shell plating, may be comparatively few in number and of light scantlings. Efficiency in the structural design of all parts, however small and unimportant, is carefully studied; if, by a more elaborate design, a part may be reduced in massiveness and yet still afford the required strengthening effect, it is so designed, regardless of the greater cost in workmanship.

Art. 184. In order to dispense with connecting angles, it is now a common practice to **flange the edges** of the various plates (see Plate 102). The tops **of the floors** are often flanged, thus dispensing with reverse bars; and in some cases their lower edges also, so as to dispense with the frame angles (Fig. 14, Plate 17, and Plate 111), but, of course, this can only be done where the bottom of the ship has no transverse curvature, for only straight edges can be flanged cold. The **intercostal plates** are very commonly flanged, usually on two sides, but sometimes on the upper and lower edges as well. And the side girders of a McIntyre tank may be flanged, thus dispensing with top and bottom angles.

The **flange system** cheapens the constructive work, for there are fewer parts to make and fit, and less riveting; the operation of **cold flanging** only occupies a few moments—however large the plate—and involves no manual labour (see Art. 539). There may be little or no saving in weight, however, for when a plate is united by a flange, it is usual slightly to increase its thickness, to compensate for the inferior stiffness of the connection. Compared with the square heel of an angle bar, the rounded knuckle of a flange has an inferior abutment and holding effect. The case of a strut or pillar may be suggested, whose ends, instead of meeting the supported part with a square abutment or palm, are bent round with an easy curve to meet it tangentially; it is evident that a tendency to shirk its work would develop under a comparatively small load. When subject to the buckling effect of grounding pressures, the floor plates are in the

position of the above strut. Experiments made (by Lloyd's Register) to ascertain the comparative merits of a flange *versus* an angle-bar connection, proved that under excessive crushing pressures the former was inferior, the plate tripping and bending more readily (see Fig. 5, Plate 18); and the inferiority became more pronounced when both edges were flanged. In view of this, Lloyd's rules require that when plates, subject to crushing or buckling stresses acting in their own plane, are connected by a flange, their thickness shall be increased by $\frac{1}{20}$ inch. In the case of flanged bulkheads, where the flange serves as a stiffener against deflecting stresses acting in a plane at right angles thereto, further experiments prove that there is no inferiority, but rather the reverse; and so here no increase is made (see Art. 212). The increased thickness in flanged plates is also useful as compensation for the injury done to the material at the knuckle of the flange. To bend sharply a cold plate is a severe ordeal; although it may withstand the treatment, evidence of the steel being in a strained condition is often given by the appearance of small cracks at the extreme ends of the knuckle; and in some cases, when the plate is thick, it may crack from end to end along the knuckle; but this should not occur with good, mild steel (Art. 558). The rules of the British Corporation require the thickness of flanged plates to be increased by $\frac{1}{40}$ inch for plates up to $\frac{15}{40}$ inch thick, $\frac{2}{40}$ inch for those of $\frac{16}{40}$ to $\frac{25}{40}$ inch thick, and $\frac{3}{40}$ inch for those exceeding the latter thickness; and to ensure ample mildness in the steel, and thus avoid the injurious straining shown by the tendency to crack, they require that the tensile strength of the steel shall not be more than 29 tons per square inch, nor less than 25 tons, the greater thickness compensating for the inferior strength and stiffness. Lloyd's rules permit of a minimum strength of 26 tons (instead of the usual 28 tons) in cold-flanged plates.

Art. 185. Lloyd's rules present a tabulated statement of the **scantlings of** the various parts **of cellular double bottoms.** An idea of the comparative sizes, in large and small vessels, may be obtained from Plate 4. The floors and longitudinals are alike in thickness, the margin plate is rather thicker, and the vertical keel still thicker. Under the boilers all bars are increased in thickness, from $\frac{1}{20}$ to $\frac{2}{20}$ inch, and all plates by $\frac{2}{20}$ to $\frac{4}{20}$ inch, as a provision against the more rapid corrosion which prevails in this region. Frame angles which do not fall upon floor plates are made the same size as those on the vessel's sides; in those which do, the vertical flange is made narrow, like the shell flange. Excepting the vertical keel and frame angles, all other angles within the tank are alike in scantlings.

The **tank top** is usually designed as **a level surface.** In some of the early double bottoms it was extended right out to the vessel's sides, but soon the now universal plan was adopted of flanging it downwards, so as to form a gutter for the bilge water, and, by the squareness of its incidence with the shell, facilitate the watertight connection. Formerly, it was common to **slope the tank top** slightly upwards from the centre line (Fig. 3, Plate 18), for by doing so the British tonnage was reduced (see Art. 85). Now this is seldom done, except in vessels which have a considerable rise of floor, where, if it were level, it would be too shallow at the margin plate or too deep over the keel; or where a small Suez-canal tonnage is required, this being still computed in the manner formerly in vogue for British tonnage. The formation is objectionable, because, in order to get rid of drainage or leakage water, wells must be provided, with central openings in the tank top. In some cases the tank top slopes downwards from the centre on either side (Fig. 2); there is little advantage in this, but it may be useful where a deep and strong vertical keel, and yet not

too large a tank, is desired. As a rule the tank top is level all fore-and-aft, but sometimes it is raised under the engine, to avoid deep engine seating and give extra rigidity and strength at this part (Fig. 1, Plate 28, and Plate 107). And sometimes it is raised towards the after end, so that, by carrying more water at this part, the propeller may be better immersed when running light (Plates 109 and 110).

Art. 186. Ballast tanks are usually filled by simply opening a valve and letting the sea water flow in. When full, the water rises in the air pipes to the sea level without. In this condition, all **buoyant pressure is transferred from the outer bottom to the tank top**; the vessel then floats upon this, so that the outer bottom, having the open sea above and below it, might be removed without affecting the vessel's flotation. Sometimes the tanks are filled by injecting water by the steam pumps (see Art. 424), in which case the water, when the tank is full, may rise above the sea level and overflow at the top of the air pipes on the upper deck. Here, therefore, the **pressure on the tank top may exceed the buoyant pressure on the shell**; it is the same as the latter would suffer were the vessel's draught increased until the sea was level with the upper deck or tops of the air pipes; the excess of upward pressure is balanced, of course, by a corresponding excess of downward pressure on the shell, the tank being subjected to a bursting pressure, as in a steam boiler. In order that the tank-top plating may withstand these severe pressures, it is evident that it must be well held and stiffened by the framework below; it need not, however, be so strong as the shell, for this has important structural duties, and is liable to intense local pressures through grounding.

In a **McIntyre tank** the inner bottom is tied down only by the fore-and-aft girders, and so, in order to check the **tendency of the plating to bulge** upwards between them, they should be placed sufficiently close together. The usual spacing, and that specified by Lloyd's rules as the minimum, is 3 feet. Even when so spaced very perceptible bulging may usually be observed when the tank is pressed with a head of water, and so, to secure a better and more uniform stiffening effect, cross stiffening angles are sometimes fitted between the girders, the latter being placed somewhat further apart (the rules of the British Corporation specify this construction). Although not introduced between all the girders, they are sometimes fitted between the margin plate and the outermost one (Fig. 5, Plate 103), for the following reason.

If the vessel remained perfectly steady, the fact of the **tank-top plating** being slightly bulged by water pressure would do no harm; under ordinary conditions, however, the rolling and pitching of the vessel causes the water to press alternately on different portions, so that there is a continuous **panting movement.** In resisting this, each girder and margin plate forms a fixed line, along which the straining effect is concentrated, and, as a result, it is not uncommon to find, when the movement has been long continued, that **fore-and-aft cracks** have developed at these places. In the region of the margin plate a variation of water pressure sufficient to cause panting may occur with every roll of the ship; for, with the tank full, the pressure would vary from zero to that due to a head of water equal to the vertical oscillation of the margin plate, and if the tank were only partially filled the resulting stress might be greatly aggravated by the concussive effects of the rushing water. The existence of such straining is often evidenced (in McIntyre tanks) by loosened riveting and cracks along the knuckle of the margin plate. It is particularly noticeable in the early-built vessels, in which margin bracket plates were not fitted on every frame (Fig. 11, Plate 17); now they are always so fitted, both inside and

out, whatever the type of tank. In large vessels (over 38,000 plating numeral), having a cellular double bottom in which alternate floors are omitted, the brackets on the intermediate frame angles are made rectangular, so as to take a three-rivet connection to the tank top (see dotted lines in Fig. 1, Plate 102).

The increased pressure and **straining effect** which **water ballast** may exert when the ship is moving is sometimes illustrated in the case of collision. Should a vessel be suddenly brought up by **end-on collision**, the water in the double bottom, tending to continue its forward movement, may cause an intense bursting pressure at the forward part of each tank. If, for instance, the forward motion of the vessel were retarded at the rate of 32 feet per second, the containing walls at the forward end of each tank would be subjected to a pressure represented by a vertical head of water equal to the length of the tank. As a result of end-on collision, it is not uncommon to find that leakiness has developed in the various joints at the forward ends of the tanks; and this, of course, may occur quite as readily in tanks near the stern as in one near the damaged bow.

Art. 187. In a **McIntyre tank, the strakes of tank-top** plating are sometimes disposed fore-and-aft and sometimes athwartships. In any case a fore-and-aft strake is usually fitted over the centre line girder, the better to maintain its character as a powerful centre keelson. If the tank top is only supported by fore-and-aft girders, the athwartship disposition (Fig. 5, Plate 19) is the better one, for then the transverse seams of the plating are reinforced by the crossing of the girders; when they lie longitudinally between them, the joints—single riveted in the usual way—may suffer from the severe transverse tensional stress which accompanies bulging pressures; further, as the seams are of double thickness they form very efficient cross stiffening ridges against bulging tendencies. As already noticed, a McIntyre tank is not usually designed to increase the strength of the hull, its strength is merely proportioned to what is suitable for a tank, pure and simple. The end joints of the margin plate are double riveted, and those of the centre girder treble; with these exceptions, all other joints may be single riveted.

The **centre girder of a McIntyre** tank is made rather thicker than the others, and is provided with double angles on both edges; as already noticed, in modern vessels having a flat-plate keel, it is sometimes worked as a continuous vertical keel (Fig. 4, Plate 103); if not, intercostal plates must, of course, be fitted. The connection of the **side girders** to the floors used only to be made by two rivets, a lug being fitted for the purpose either on the girder or the floors, now a four-rivet connection is always made, by **double lugs**, one on the floor and one on the girder (Fig. 1, Plate 103). The insufficiency of a two-rivet connection is often observed in old vessels, where the girders (after long exposure to the concussive effects of free water) may be found to have severed all connection with the floors, and, by the friction of their side straining movement, worn away the reverse frame and their own angles. Sometimes, instead of double lugs, a single vertical one is fitted, which not only ties both parts together, but serves to stiffen and hold them erect (see Fig. 5, Plate 103). In this type of tank the transverse bulkheads usually pass right down to the shell, the centre girder, margin plate, and a girder on either side piercing it, but the others and the tank-top plating abutting on the bulkhead. If a 'midship bulkhead forms the termination of the tank, as shown in Figs. 2 to 5, Plate 19, care must be observed that the abrupt stoppage of so much longitudinal material does not cause a transverse line of pronounced relative weakness. The side and bilge keelsons should pierce the bulkhead and run into the tank for several frame spaces, so as to scarph with the

girders and margin plate. And each girder should be represented beyond the tank by a long vertical bracket plate, so as to avoid all sudden discontinuities.

Art. 188. The thickness of the **tank-top plating** (whatever the type of double bottom) varies according to its location; in the engine room it is made $\frac{1}{20}$ to $\frac{2}{20}$ inch thicker than in the holds; and in the boiler space $\frac{3}{20}$ to $\frac{4}{20}$ inch thicker, to provide against the rapid corrosion of this part (see Art. 465). In a **cellular double bottom** the strakes are always arranged longitudinally. In shipyards where the tank top is fitted after the shell plating, athwartship tank-top plates are usually introduced below the bulkheads, from margin to centre strake (Fig. 4, Plate 22, and Plate 88), so that the latter may be erected at any time, in which case the ends of the fore-and-aft strakes are connected to the transverse with treble riveted joints. The centre strake is worked continuously, and as it forms the upper flange of the vertical keel, it is made thicker than the others, and its joints are double riveted. In small vessels the **fore-and-aft seams,** excepting those of the centre strake, are single riveted; so also are the end joints, except those in the machinery space and those of the centre strake and margin plate. In larger vessels (over 20,000 plating numeral), all the end joints for half length amidships are double riveted, and in still larger (over 30,000 plating numeral) all fore and aft, and, according to the vessel's size, the fore-and-aft seams, near the centre line or all of them, are double riveted for half length. In case of grounding, the upward pressure on the bottom places the tank top in transverse tension, tending to pull its fore-and-aft seams asunder and to open the upper parts of the joints of the severed floor plates (Fig. 7, Plate 2). Accordingly, when the longitudinals are continuous, it is well that the strake of tank-top plating immediately over each one should project equally on either side, the better to unite the severed floor plates; if a seam lay alongside a continuous longitudinal, it would aggravate the transverse weakness due to the severance of the floor plates. The transverse tensional stress is greatest at the centre line, and it is in view of this, and of the fact that the floors are severed here, that the edges of the centre strake are always double riveted.

Art. 189. In merchant vessels the longitudinal or **intercostal plates** are usually **disposed in straight lines,** parallel to the keel. Towards the ends, where the margin plate converges upon them, they stop, each one short of it (see Plate 88). The additional intercostal plates introduced in the engine room stop short at either end of it. The longitudinals are usually disposed vertically, so as to avoid bevelling their upper angles, but if the tank top is not level, square either to it or to the shell. Whatever the inclination, it is maintained all fore and aft, so that the intersection of each longitudinal with every floor is represented on the scrive board by one line (see Plate 79). The constructive work is thus facilitated, because many of the floors may be made from the same template; if the inclination varied, the longitudinals would meet each floor at a different angle, their intersections showing on the scrive board as numerous, confusedly intersecting lines. For the greatest efficiency, all framework should lie square to the surface it is designed to support, because pressures acting on the latter can only do so at right angles thereto. But, to incline the longitudinals, so that they may be everywhere square to the shell, would greatly complicate the constructive work; amidships, where the bottom suffers the most severe pressures, they do lie practically square thereto, and towards the ends any little divergence is unimportant, for, of course, in any case, they are held erect by the numerous floor plates.

In **warships** the **longitudinals** are not disposed in the foregoing

simple fashion; they are curved inwards towards the ends, and, to conform with the fore-and-aft bulkheads or engine-seat bearers, they may be sharply bent, presenting in plan, irregular crooked lines. Of course, when acting as longitudinal stiffening ribs, a departure from a fair fore-and-aft line does not affect their efficiency. As the framework of a warship is slender, it is important that its efficiency should be as perfect as possible; its capabilities are, therefore, wisely increased, by disposing the longitudinals everywhere square to the surface they support; here, of course, simplicity and economy of construction are minor considerations. When the longitudinals are square to the shell, they are also square to the inner bottom, for in these vessels this is usually worked parallel to the shell (see Plate 113).

Art. 190. At one time it was common not to **sever the frames at the margin plate**, but to run them through and secure watertightness by means of collar angles in the manner shown in Figs. 11 and 12, Plate 17, for it was feared that to cut them would injure their strength and increase and complicate the constructive work. Now, of course, they are always severed, a connection being secured by large bracket plates (Figs. 13 to 18), except in the case of deep tanks, where it is still sometimes preferred to run them through intact, or with a part removed to facilitate the making of the collars (Figs. 4, 5, 7, Plate 53, and Figs. 2 to 10, Plate 55). In the first vessels, in which the **frames pierced the margin plate,** no brackets were fitted on the outside of the latter, for, with continuous frames, there appeared to be no need for them (Fig. 11, Plate 17). But they were soon found to be necessary, because in their absence there was nothing to stiffen the bilge, whereas in a ship with ordinary floors there was the tapered floor head. And, moreover, the mere presence of a double bottom calls for increased strength at the bilge, because of the sudden variation in the structural rigidity, where the deep bottom framework gives place to the comparatively slender side frames, and because the weight of the concentrated mass of water in the tank tends, when the vessel is in lively movement at sea, to cause intense local stresses at this part.

When bracket plates are fitted to the frames on either side of the margin plate, the extensiveness of the connection so secured at once permits of the frames being cut, with the beneficial result of avoiding all costly watertight collar angles, their place being taken by a straight fore-and-aft angle bar, easily fitted and caulked. Nevertheless, when brackets were first introduced the continuity of the frame angles was still very commonly maintained (Fig. 12, Plate 17), and even now, in the case of deep tanks, the frames are often carried through and bracket plates fitted to give rigidity at this part and to compensate for the severance of the reverse bar or for the removal of the inner flange in the case of Z or channel frames. When the frames are severed, they are usually cut in the first instance and erected in separate pieces, but when there are only a few, as in way of a deep tank, they may be made in one piece, and be cut by hand, in the ship, before fitting the tank top plating; this is advantageous in that the frames are then more easily made, erected, and faired, the cost of cutting them by hand being a small matter; in some cases, however, to save hand cutting, they are partially severed before erection.

Art. 191. The methods of **securing watertightness by collar angles,** where frames of different kinds pierce watertight plating, are shown in Figs. 2 to 10, Plate 55. Fig. 2 illustrates a method formerly employed in the peak tanks of small vessels, by which the making of watertight angle collars is avoided. A continuous gunwale bar and stringer lugs are fitted in the usual way; cast-iron chocks are then made, one

for each frame space, and fixed in place by a couple of bolts through the stringer. To save metal, the chocks are hollowed, trough-like, and all around the upper edge there is a check, into which cast-iron turnings or borings are forced; the latter are then moistened with salammoniac, which, by causing rapid rusting, transforms them in a few days into a hard, solid mass, perfectly watertight and enduring. The whole may then be covered over with Portland cement. With a built frame it is difficult so to form the collars that they may fit with precision into all the irregularities of the section (Fig. 4); it is, therefore, usual in such cases, to remove the reverse bar in way of the collar, and, as compensation, fit bracket plates to the deck (Figs. 4 and 5, Plate 53), or double the frame angle, making it of T section (see Fig. 5, Plate 55), or fit a thick strap on the transverse flange (Fig. 6), tapered where it passes between the reverse bar and frame. Wherever two conjoined parts pass together into a tank, any imperfection in the contact of their faying surfaces may form a conduit for the passage of water from the tank. To prevent this, a *stopwater* of soft packing must be introduced; it is required, for instance, between the frame angle and the shell, and the frame angle and its reverse bar or doubling (see Art. 326).

When, in the case of a deep tank, a **bracket** is fitted **in conjunction with a continuous frame**, the reverse bar or inner flange of a Z or channel frame may, of course, be cut without compensation; and as the brackets give very superior transverse strength and rigidity, they need not, in such cases, be fitted on every frame. The watertight collars in way of such brackets used often to be fitted staple fashion (see Fig. 12, Plate 17, and Fig. 4, Plate 53), so as to surround each bracket, and thus prevent water from finding an exit by travelling between the edge of the latter and the tank-top. The better plan, however, is to increase the size of the bracket and cut away its inner corner, so as to permit of an ordinary collar being fitted around the frame angle only (see Figs. 5 and 7).

Art. 192. As regards the **connection of the frame brackets to the margin plate** of a double bottom, the requirements of Lloyd's rules are as follows: In small vessels all brackets are connected by a single angle (Fig. 2, Plate 17). If over a certain size (30,000 plating numeral), those for half length amidships are connected by double angles, every fourth one being additionally secured by a horizontal gusset plate, connecting its upper edge to the tank top (see Fig. 3). In still larger (over 40,000 plating numeral), the double angle connection is extended over three-quarters of the vessel's length (measured from the collision bulkhead), gussets being fitted at every third bracket (Fig. 4). In the largest vessels (over 50,000 plating numeral), double angles are fitted all fore-and-aft, and gussets at every second bracket (Fig. 5). In vessels in which hold beams are omitted in favour of web or deep framing, and where, therefore, owing to the greater depth of unsupported side, the tank margin connection is more severely tried, the requirements as to double angles and gussets come into operation in smaller vessels (those over 20,000 plating numeral). In many cases, instead of fitting double angles, it is preferred to fit a single large one, having flanges sufficiently broad to take two rows of rivets (see E, Fig. 7, and Plate 106). In some cases the gusset plates are made rectangular (Fig. 1, Plate 17). In large vessels, to avoid fitting numerous small gusset plates, a fore-and-aft tie plate is sometimes introduced, projecting from the tank margin plate and connecting to all the brackets (Fig. 6); and in some cases tie bars of tee or angle bar are substituted for the gussets (see Figs. 16 and 17). As the rivets connecting the gussets to the tank margin plate are liable to intense stress, they should be absolutely sound, and to ensure this, therefore, Lloyd's rules specify that they shall not pass through the landing

edge of the margin plate, for then they would be three-pliers, and the caulking edge of the landing, if below the bracket, could not be caulked. To comply with this requirement, the margin plates must have a wider flange than is otherwise necessary, which circumstance increases the difficulty of making and fitting those which have fore-and-aft curvature.

Formerly Lloyd's rules did not require gusset plates as above, but the rivets connecting the angles to the margin plate were so often found to strain, and cause leakiness in the tank, that it became evident that the margin of strength in modern, broad-beamed vessels was too small. Formerly, when the connection was made by a single angle, it was always made to face the opposite way to the one within the tank, for then, none of the rivets being three-pliers, their soundness and watertightness were more assured (see A, Fig. 7, Plate 17). But Lloyd's rules now require these particular angles to be placed opposite each other, so that the floor within the tank and the bracket plate without may receive a direct through connection (see B, Fig. 7). The circumstance that the rivets, being then three-pliers, are less likely to be sound and watertight, is one, of course, which can be met by careful workmanship. In many cases, however, to avoid these three-ply rivets (which tend to hinder and complicate the structural work), it is preferred to reverse the angles, and, as compensation for their inferior holding effect, increase their thickness and make the tank margin flange of one or both sufficiently wide to take two rows of rivets. This is particularly desirable at the vessel's ends, where to place them opposite each other necessitates in one of them a very close bevel, and, consequently, a difficulty in securing good rivets (Fig. 8). The connection, as formerly made, was less rigid and secure than that now in vogue, as will be evident from a comparison of the exaggerated straining depicted in Figs. 9 and 10. As a result of long continued straining of this kind, the margin plate often cracked across close to the connecting angles. An excellent remedy for such straining is to increase the thickness of the margin plate and angle bars. In view of the excessive panting stresses and blows to which the bows of modern cargo vessels are exposed, it is common to increase the connection of the frames to the margin plate at the forward end, by doubling the angles or fitting a large double-riveted single one (E, Fig. 7) and by additional gusset plates.

Art. 193. The security of the connection to the margin plate depends much on the depth of the latter, for not only does a deep margin plate permit of more rivets, but of more capable ones, due to the greater leverage or moment of resistance of the uppermost (see Art. 34). The **depth of margin plate** specified in Lloyd's rules varies from 18 inches in a small vessel to 34 inches in a large one, but a reduction is permitted at the fore and after ends (where racking stresses are less intense) of 10 and 15 per cent. respectively. The depth of a tank at its margin has a considerable influence on its form and dimensions; thus, with a given depth of vertical keel and the requirement of a level tank top, it **may limit the breadth of the tank**; for if the vessel has a large rise of floor, then, in order to secure the required depth of margin plate, the breadth of the tank may have to be so small as unduly to limit its capacity for water ballast; to avoid this, the depth at the keel must be increased, or the tank top sloped upwards towards the bilge (see Fig. 3, Plate 18). The breadth of the tank is also sometimes governed by the circumstance that, should a certain limit be exceeded (34 feet by Lloyd's rules), a second line of intercostal plates becomes necessary (Plate 4). Or it may be desired to place the margin plate so far in from the bilge that the frame angles within the tank may be straight (Fig. 14, Plate 17, and Plate 111), and thus avoid the

necessity of bending the bottom frame angles, or permit, if required, of the lower edges of the floor plates being flanged. Otherwise, it may be desired to place the margin plate so far up the bilge as to do away with any sharp curvature in the heavy side frames, or to permit of the bilge keel being placed within the tank, where, should it tear away and damage the shell, the entering water would do no harm (Fig. 13, Plate 17). In fine-lined vessels the double bottom towards the bow and stern may become so narrow as to be of little use either as a receptacle for water ballast or as a means of safety; and on this account it is sometimes discontinued some distance from the peak bulkheads, in favour of the more simple framework of a single bottom. Otherwise, when extended to the ends (the peak bulkheads), its breadth may be maintained by increasing its depth, or sloping it upwards on either side.

The **margin plate** may be disposed everywhere **square, or nearly square, to the shell,** so as to avoid the bevelling of the shell angle; or it may be disposed at the same inclination throughout, so that its flange may have the same bevel all fore and aft. In the latter case the inclination chosen is the one involving the least average bevel in the shell angle. In order **to avoid** the necessity of impressing **fore-and-aft curvature** on the separate margin plates, the fore-and-aft contour of the tank top near the bow and stern, instead of being fairly curved, is very commonly made up of separate straight lines, one for each plate (see Fig. 2, Plate 89). This greatly simplifies the making and fitting of the margin plates, especially when they are long, because to bend a flanged plate lengthwise is a troublesome operation, and involves furnacing. When so arranged, all the necessary shaping may be done in one operation, in the cold-flanging machine. Otherwise the margin plate may be arranged as shown in Fig. 3 (Art. 515). In twin-screw vessels, where the engine-seat plating may project beyond the margin plate, double angles may be substituted for the flange. At one time the continuous shell angle was often placed within the tank, and as it cannot be caulked when so disposed, its watertightness was secured by soft packing; indeed, caulking was sometimes dispensed with even when it was placed outside (Art. 325).

Art. 194. The **depth of the double bottom** varies from about 3 feet in a small vessel to 4 feet in a large. In some modern Atlantic liners, however, it approaches 5 feet, and where raised under the engines, it may be 8 or even 9 feet deep. In large vessels the volume of water ballast contained in a double bottom of the usual depth of about 4 feet is insufficient to immerse the vessel properly when light, and although, on this account, it would be advantageous greatly to increase the depth of the double bottom, it is undesirable to do so on account of the accompanying reduction in the capacity of the holds for measurement cargoes. When it is desired, therefore, to **carry more water ballast,** the necessary provision is made by **supplementary deep tanks,** which, of course, may also serve as cargo spaces. Modern vessels are now frequently provided with two large deep tanks, having a combined capacity equal to or exceeding that of the double bottom (Figs. 6 and 7, Plate 20); in large cargo vessels the latter alone usually contains water ballast equal to about 15 per cent. of the vessel's dead-weight carrying capacity (Art. 172). In small vessels the depth and capacity of the double bottom are relatively large, the question of accessibility preventing a reduction in its depth proportionate to the small size of the hull; in a large vessel the governing requirement is a sufficiently deep and strong vertical keel. In very small vessels the comparatively great depth of the double bottom, while giving a large capacity for water ballast, greatly reduces the hold space for measurement

cargoes, and, accordingly, when space is particularly required, the double bottom is only fitted locally, usually in the after hold, so that the trim, when light, may be by the stern, and thus ensure good immersion of the propeller.

Art. 195. Nearly all modern vessels have a **double bottom** all **fore and aft**, but it is now common, in cargo vessels, to **dispense with it under the boilers**, in order to avoid the rapid corrosion which generally occurs at this place (see Art. 465). In such cases the ordinary framework of a single bottom, *i.e.* shallow floors and keelsons, may be adopted; but it is better, and more usual, in order that there may be no break in the continuous strength and rigidity of the bottom, to retain the tank framework, providing, however, in the top plating numerous large manholes or ventilating openings. If ordinary shallow floors are fitted, care must be taken to scarph the keelsons and tank longitudinals in such a manner that there may be no sudden break in the longitudinal strength.

Art. 196. A **double bottom** is usually **subdivided into several tanks**, one for each compartment in the hold, so that each bulkhead is represented by a watertight division in the double bottom. In some of the early iron vessels there was only one division, or even none; this, of course, was economical, for it saved the work of making the divisions and simplified the piping and pumping arrangements. A large tank is objectionable, because, if not quite full, the large **free volume of water** may have a dangerous **heeling effect**, and, having so large a range of motion, the energy which it might acquire would be liable to damage the structure. Moreover, owing to the longer period occupied in filling such a large tank, these dangers would be more likely to occur, for the critical period, when in a semi-filled condition, would not quickly pass. Subdivision is useful, in that by filling certain tanks the amount of ballast may be varied and the vessel's trim nicely adjusted. In a cellular double bottom the watertight divisions are formed by an intact floor plate, having all around its edges a watertight angle-bar frame, neatly fitted with welded corners (see Figs. 1 and 2, Plate 18). Sometimes, to permit of access through these floors, they are provided with manholes having watertight covers. When the longitudinals are continuous there is a separate watertight frame for each portion of the floor between them (Fig. 1). The divisions are usually placed directly under the transverse bulkheads, but sometimes they are shifted one or two frame spaces before them in the after body and abaft them in the fore body, this being advantageous in simplifying the pumping arrangements and avoiding some three, and four-ply watertight riveting (Figs. 4 and 7, Plate 22). In many vessels wells are provided in the double bottom, one at the after end of each hold, but more particularly at the after end of the machinery space. As noticed in Art. 420, these are simply small transverse sections of the double bottom, cut off therefrom and open to the hold.

In modern vessels, one or more of the **double-bottom tanks** is often used for carrying **fresh water** for the boilers, or drinking water for cattle, or, in passenger vessels, for washing, drinking, and cooking purposes. As already seen, a ballast tank should always be quite full; but when used as a reservoir for fresh water, a semi-filled condition may prevail as often as a full one, and, accordingly, tanks which are intended for this purpose should be small, for then, even though the water should dash about, it can acquire no dangerous momentum, and its heeling effect is small. The necessary reduction in the size is usually secured by making the vertical keel watertight, a simple matter, as the only modification required is the caulking of the top and bottom angles, and the omission of limber and air holes. **A centre-line division** is advantageous, in that it greatly **reduces the heeling tendency**

(Art. 54). The double bottom under the machinery space is very commonly divided in this way, for in most vessels it is used for fresh water for the boiler feed; and in some cases an additional transverse division is introduced, giving, with the centre-line division, two tanks under the engine and two under the boilers. In large passenger vessels it is common to make the vertical keel watertight throughout, except in the narrow foremost and aftermost tanks; this is useful not only in adapting the tanks for the carriage of fresh water, but for trimming the ship should she at any time take a list, through consumption of coal or one-sided stowage. Such minute subdivision, however, complicates the pumping arrangements, and so is not adopted in ordinary vessels. In warships the vertical keel and one or more of the side longitudinals are always watertight, for the greater the subdivision, the less serious the effect on the vessel's flotation of damage to the outer shell. Besides, in those vessels there must be ample means of correcting a list, for should this occur in action the guns might not be properly worked, and the side armour and protective deck might rise above the water on the one side, and sink below it on the other.

Art. 197. The floors and longitudinals must be so perforated that when the tanks are filled or pumped out the water may readily flow from cell to cell. The entrance of water involves the exit of the same volume of air, and so provision must also be made for the passage of the latter from cell to cell, so that it may find its way to the air pipes provided for its escape. For the passage of water, **limber holes** are provided in the lower margins of the floors and longitudinals, also **drain holes,** flush with the surface of the cement (Art. 90). The necessary **air passages** are provided in the upper parts of the floors and longitudinals, so that when the water rises above the manholes the air may still have ample means of escape, and nowhere check the rise of the water and the complete filling of the tank. For this purpose it is usually sufficient to omit small portions of the liners fitted below the outer strakes of the tank top plating, but it is well also to provide 3-inch holes in the upper margins of the floor plates, so that when cleaning or repairing work is being done in the tank the hot vitiated air may flow readily from cell to cell, to escape through the manholes in the tank top (see Plate 105).

Art. 198. For access to the double bottom, **manholes in the tank top.** There should be at least four in each tank, one at each end, on either side of the vertical keel, so as to form an inlet and outlet for a proper circulation of air when work is being done in the tank (Plate 88). When there are manholes in all the longitudinals, the whole tank might be accessible through one hole in the tank top on either side, but it is well to provide a number. When the longitudinals are not extensively pierced, it is well to place a manhole near each end of each fore-and-aft space bounded by longitudinals, so that a man, when making an inspection of the tank, may pass from end to end of each space, missing no part, and nowhere retracing his steps; to pass through the longitudinals to examine the wing portions of the tank may involve a toilsome search for the one or two manholes provided for such passage. The practical details of watertight manholes and hatchways are described in Art. 416.

Art. 199. The end **bulkheads of deep tanks** must be particularly well stiffened by strong bulb-angle bars or deep flanges, and by horizontal girders (Plates 24 and 25). When flanges are adopted, the horizontal girders in small tanks may be fitted in the manner shown in Fig. 1, Plate 24. This is an advantageous arrangement, not only in the matter of strength, but, as all the stiffening material is on one side, it simplifies the caulking of the bulkhead. In bulkheads of great depth the

seams of the plating are double riveted. The beams of the watertight deck, forming the crown of the tank, are of the usual deck-beam size, placed on every frame, a well-pillared intercostal girder being fitted below on either side. Where stiffening bars or side stringers abut upon or pierce the containing walls, they are connected thereto by large brackets, for, as it is at the juncture of the tank walls that straining effects due to water pressure—statical and dynamical—are concentrated, large bracket plates, by holding the parts at fixed angle, are most useful in increasing their capabilities (Art. 210). In oil vessels the shell lugs of the intercostal side stringers are usually doubled in way of the bulkheads (or all fore and aft in the case of large tanks; see Fig. 11, Plate 26), for it is found that, with ordinary single lugs, the shell rivets are liable to strain. If the tank be not quite full, the water, lashing from side to side as the vessel rolls, is brought up, or "chocked," in the corners below the tank top, and, as a result, it is not uncommon to find the rivets of the beam knees loosened or broken, as also the shell rivets in way of same; for this reason the beam knees of deep tanks are now always made three times the depth of the beams themselves, in place of two and a half times, as formerly, and the frame-to-shell rivets throughout the tank are spaced 6 diameters apart, instead of the usual 7 diameters. The fore-and-aft centre-line bulkhead must also be well stiffened (see Plates 24 and 25), for it may be exposed to the battering effect of free water, and it takes the place of a centre row of pillars; and it must be well connected at the top and bottom by double angles and brackets to the stiffeners. In many early cases, where the connection was meagre, the bulkhead was swept down by the moving water. If the tank is abaft the machinery space (Plate 110), the shaft tunnel, passing through it, must be well stiffened with bulb-angle bars; sometimes the stiffeners are placed outside, to facilitate the caulking. If the tank is not intended to be used for cargo, as in the peaks, only a small manhole is provided in the top plating, otherwise a watertight hatchway is fitted, in size about 8 or 10 feet square, one on either side of the centre-line bulkhead. In the case of peak tanks, if the tank top is not more than 1 foot above the load water-line, and if access is only provided by a manhole, the volume of the tank is not included in the tonnage. Other matters in connection with ballast tanks and the tanks of oil vessels will be found in Arts. 172 to 175 and 233.

CHAPTER XV.

Art. 200. The term "**bulkhead**" is used indifferently for all vertical partitions, whether of wood or iron, but more particularly for the important transverse ones which subdivide the hold into separate watertight compartments. The latter must be strongly constructed, so that, should they be called upon to fulfil their primary purpose of confining water, they may withstand its bursting pressure. Those which are not watertight are fitted with a view to subdividing the hold as a cargo space, or to form retaining walls for coal bunkers, and, as they are not liable to water pressure, they may be comparatively slender. Bulkheads are useful in three ways—as *watertight divisions*, as *fire screens*, and as *structural diaphragms*. In the first capacity they may confer immunity from foundering, for should water enter the ship as a result of damage to the shell, it may be confined to the one hold; in the second, they may, should the cargo take fire, confine the conflagration to the one hold, facilitating its extinction and limiting the damage. In the above two capabilities their usefulness is only potential, for they may never be called upon to display their capabilities; but in the third, as structural diaphragms, they are at all times beneficial, for, by rigidly uniting the vessel's sides, deck, and bottom, they are most efficient in checking any tendency to alteration in the form of the transverse sections, due to racking or panting stresses.

Although bulkheads may give **immunity from foundering**, their capabilities in this respect are dependent on many circumstances. If the subdivision of the hull were insufficient, so large a volume of water might enter that, although confined and limited, it might still sink the ship. Also, should the bulkheads be weakly constructed, they might collapse under the water pressure; or they might not be thoroughly watertight, or this quality might be destroyed by blows struck by cargo washing about in the hold. Further, if the cargo were one of a highly absorbent nature, such as grain, cotton seed, hemp, etc., it might swell so much with the water as to injure the bulkheads. Instances have occurred where the hull has been seriously damaged, the decks and bulkheads being torn and displaced, by the powerful swelling action of such cargoes.

Although in many existing vessels the arrangement of bulkheads is such as to give little assurance of immunity from foundering, there is one bulkhead, the foremost one, termed the "**collision bulkhead**," whose efficiency is undoubted (Plates 10 and 20). It is fitted for the distinctive purpose of serving as an inner skin should the bow be broken open by end-on collision; its efficiency is assured because, owing to the smallness of the peak compartment, so little water may enter that its effect on the vessel's flotation is unimportant, also, being of small area, the bursting pressure it may suffer is small, and, being narrow, it is naturally strong and capable. Of course, the above assumes the integrity of the bulkhead to be unaffected by the damage done to the bow, a condition which can only be

assured by placing it sufficiently remote therefrom. A distance of one-twentieth of the vessel's length is generally regarded as a safe minimum, and is that specified by Lloyd's rules. The usefulness of the collision bulkhead is constantly shown; cases of vessels putting into port, with their bows damaged and the peak full of water, being sometimes of weekly occurrence.

The importance of the collision bulkhead was recognized at an early period; it was sometimes attempted to fit them in wood ships. When iron took the place of wood, the ease with which they could be fitted was at once taken advantage of, and collision bulkheads were forthwith regarded as essential. Lloyd's rules for 1855—the first for iron vessels—required that a collision bulkhead should be fitted in all vessels, both at the bow and stern. Subsequently it was observed that the stern of a sailing ship was not a part liable to be damaged, and so the fitting of it here was discontinued. In screw steamers there is always an after-peak bulkhead, but here it is necessary owing to the presence of the propeller shaft.

The possibility of the cargo taking fire, through juxtaposition with the boiler furnaces, makes it imperative that the **machinery space** shall be separated from the holds by iron **bulkheads.** This was recognized at an early period. It was required by the Merchant Shipping Act of 1854, which also specified a collision bulkhead, and, in screw steamers, one at the after end. Although in these early vessels the bulkheads were caulked, they were of very doubtful utility in conferring immunity from foundering, for they did not always extend sufficiently high, and were often so weakly constructed as to be incapable of withstanding water pressure.[1] Further, with only two cargo holds, each one represents so large a portion of the vessel's interior that the *bilging*[2] of either would usually result in foundering. Although in sailing ships there has never been any statutory enactment requiring more than the collision bulkhead, some of the earlier were provided with one or two amidships; presumably they were intended to act as watertight partitions, but, like those in the existing steamers, they did not always extend to the upper deck, and were too slender to withstand water pressure.

Art. 201. It will be well to notice here the various circumstances upon which depends the **floating power of a subdivided ship** (see Figs. 10 to 13, Plate 20). The above-water portion of the hull at load draught represents **reserve displacement or buoyancy,** and whatever the volume of the actual displacement lost by the bilging of a compartment, it must be made good by a partial submergence of this part (see Art. 576). The bilging of a compartment not only destroys its contribution of displacement or buoyant force, but renders useless the reserve buoyancy directly over it; evidently, for as the vessel subsides the water is free to rise to any height within; it rises, of course, to the level of the sea without, *i.e.* to whatever water-line the vessel assumes as a result of the bilging. Theoretically, so long as the size of the bilged compartment is not such as to cause a loss of displacement greater than the reserve buoyancy existing before and abaft it, the vessel might still float (Fig. 13); but, of course, should all the reserve buoyancy be lost, she could not ride the waves, and, if the bilged compartment were not amidships, she might float with one end completely submerged, or even end-up.

The **alteration in trim** that results from the bilging of a compartment is an important matter, for, in a well-designed vessel, it is this that regulates

[1] See two papers by Mr. James Dunn, and the discussions thereon, *Trans. Institution of Naval Architects,* 1882 and 1883.

[2] "*Bilging*" is the term commonly used in referring to the flooding of a compartment consequent on damage to the shell.

the position of the bulkheads or the size of the various holds. To understand the matter clearly, consider the shape of the block-shaped vessel shown in Fig. 10, Plate 20. The darkly shaded area amidships represents the buoyancy—or displacement—lost in the bilged compartment, the force of which is represented in magnitude and position by the thick arrow F; this is shown pointing downwards, for, of course, the loss of a force is equivalent to the addition of an equal one, acting in the opposite direction; if preferred, the arrow may be taken to represent the weight of the water which enters and rises to the normal load-line. This lost displacement is made good by a call upon the reserve buoyancy, *i.e.* the vessel subsides until the two shaded areas before and abaft the damaged compartment are equal to the black one; their buoyant force is represented, in magnitude and position, by the two small arrows *f*, which, taken together, are, therefore, equal to the black one, and as they are equidistant therefrom, their combined effect, resultant force, or centre of gravity, lies directly over it, as shown by the dotted arrow; and as these—the forces represented by the dotted and black arrows—are equal and opposite, and as they are the only two forces brought into operation by the bilging, the vessel must be in equilibrium when floating at the new water-line *wl*. It should be observed that the portion of the hull immediately above the bilged compartment is the reserve buoyant part of the hull rendered useless by the bilging; the sea is here free to rise, but has no effect on the vessel's flotation.

If, now, the bilged compartment were situated forward, as in Fig. 11, Plate 20, the vessel would trim by the bow, and as the lost displacement is forward, its equivalent as contributed by the reserve buoyancy must also be forward. It must be so situated that its centre of gravity is directly over that of the lost displacement, that is to say, the new water-line *wl* must be such that the two forces f^1 and f^2 combined shall equal the force F, and be so situated that their centre of gravity or resultant, as shown by the dotted arrow, shall fall directly over it.

If the bilged compartment were the fore peak, as shown in Fig. 12, Plate 20, it is clear that, as all the volume of reserve buoyancy is abaft it, no amount of trim by the head could cause it to yield a counterbalancing force directly over. The new water-line must, therefore, take the position *wl*. At the stern this falls below the normal water-line, and, in effect, causes a further loss of displacement, as shown by the small triangular darkly shaded area or arrow F^1; and as the centre of gravity of the two darkly shaded areas (*i.e.* the two volumes of lost displacement), as shown by the black arrow F, falls directly over that of the lightly shaded area (representing the contribution of reserve buoyancy), there is equilibrium as before. The lightly shaded area is, of course, equal to the two darkly shaded ones combined.

In order that the upper deck may nowhere sink below the surface, the end compartments must be smaller than those amidships. In a block-shaped vessel, if a bilged compartment were amidships, so as to cause no change of trim, as shown in Fig 13, Plate 20, it might equal in volume the whole of the reserve buoyancy before and abaft it, the submergence bringing the deck level with the water-line, but nowhere below it. If, on the other hand, the bilged compartment were forward, so as to cause the vessel to trim as shown in Fig. 11, then, while the deck at the stem might fall level therewith, at the stern it might neither rise or fall; in a block-shaped model only about half of the reserve buoyancy would then be in requisition, and, accordingly, the bilged compartment, causing such a trim, could only be about half as large as the 'midship one just noticed.

To float with any degree of safety, a vessel's upper deck must nowhere

approach too near the surface (Art. 56). If a 'midship compartment were bilged, so that the trim were unaltered, then, although the freeboard might be small, the reserve buoyancy, whatever its volume, would be so well distributed as to preserve in great measure the weatherly and navigable qualities; owing to the sheer the bow and stern would stand well out of the water, giving good lifting powers, and the propeller would be well immersed. If the bilged compartment were situated forward, so as to cause a trim by the bow, then, although the reserve buoyancy might be large, the condition might be critical; for, with the forward part of the deck so near the surface, head seas might sweep the deck, and, with the propeller out of the water, the steaming power might be nil. The question, how close to the surface the upper deck may sink while maintaining reasonable safety, is one not readily answered. The **Bulkhead Committee**, whose investigations are noticed later, concluded that so long as it did not, amidships, fall nearer than 3 per cent. of the moulded depth, the vessel might be considered as being still navigable in moderate weather. They also concluded that, should there be a trim by the bow or stern, it might subside still nearer to the water surface; at the extreme ends, twice as near, or $1\frac{1}{2}$ per cent. of the moulded depth. These two limiting freeboards regulate the position of what the Bulkhead Committee termed the "*margin-of-safety line*," *i.e.* an imaginary sheer line, so situated on the vessel's side that amidships it is 3 per cent. of the depth below the upper deck, and at the stem and stern one half of this. If, in the bilged condition, this line did not sink below the surface, it was concluded that the vessel might be considered as reasonably safe in moderate weather.

Art. 202. In the foregoing, the *effect of cargo* is neglected, for it is assumed that the water entering a bilged compartment occupies every part of it, and so destroys all the displacing or buoyant power of this region. It is evident, however, that if the compartment were densely packed with goods of a non-absorbent character, little or no water would gain access, and thus the injury to the shell would have little effect on the vessel's flotation.

It is clear, therefore, that the efficiency of the subdivision depends very greatly upon the stowage and nature of the cargo. A cargo of lead or pig iron would require very minute subdivision, for each hold, although heavily laden, would be comparatively empty; although small in reality, they would virtually be of large size, for they would admit a large volume of water. On the other hand, with a bulky cargo of a water-excluding character, a very limited subdivision might suffice, for the cargo itself would take the place of the shell in displacing water and conferring buoyant power. In their water-excluding properties cargoes vary in infinite degree; lead or pig iron might be taken as the one extreme, and oil as the other. If an oil-tank hold extends above the load water-line, the bilging thereof would actually result in an increase of buoyancy, for part of the oil would run out and lighten the ship. Together with the character of the cargo, its disposition or stowage has evidently a commanding influence in deciding the efficiency of the existing subdivision, for, according as the bilged compartment happened to contain much or little, the vessel might be in a condition of comparative safety or of great danger.

The **efficiency of the subdivision also depends on how deeply the vessel is loaded.** If in light trim, the large above-water hull would represent so great a volume of reserve buoyancy that a large call might be made upon it and a great change of trim occur without seriously affecting the floating power. If deeply loaded, contrary conditions would prevail; there would be little reserve of buoyancy, and a small change of trim

might endanger the vessel. The special immunity from foundering enjoyed by vessels in light trim is often evidenced; in cases of collision, if the ship struck is heavily laden, foundering is the usual consequence, if light, she may be able to make the nearest port. It is very important to notice that an **insufficiency of transverse stability** may render useless the bulkhead subdivision; for the bilging of a hold may so much reduce the area of buoyant waterline plane as to make the metacentric height a negative quantity, and so cause the vessel to capsize.

Art. 203. It is evident that the **bulkheads must extend well above the level of the sea without,** for if not, as the water rose in the bilged compartment and the ship subsided, it would flow over them and fill the adjacent holds. In the earlier vessels this was not sufficiently realized, and the bulkheads often terminated at the second deck, which, although above the normal load-line, was below the water-line in the bilged condition. Fig. 9, Plate 20, depicts a vessel suffering from the circumstance of insufficient height in one of her bulkheads.

Lloyd's rules as regards subdivision by bulkheads are now much stricter than formerly; they are shown graphically in Figs. 1 to 8, Plate 20. As there shown, steamers under 220 feet in length need only have a collision and after-peak bulkhead, and one at either end of the machinery space, giving four or three according as the machinery is amidships (Fig 2) or at the stern (Fig. 1). If 220 feet long, they must have four, one of which, when the machinery is at the stern, is placed midway between the collision bulkhead and the forward end of the machinery space (Fig. 3). In steamers 280 and under 330 feet in length (Fig. 4), an additional bulkhead is required at about the middle of the fore hold, making five in all. The subdivision of the fore hold is thus regarded as more important than that of the after one, for, while the bilging of the latter might not have fatal results, that of the former probably would have, due to excessive trim by the head. In steamers 330 and under 400 feet in length (Fig. 5), another bulkhead is required in the after hold, making six in all; when 400 and under 470 feet in length (Fig. 6), seven bulkheads are required; when 470 and under 540 feet (Fig. 7), eight; and when 540 and under 600 feet (Fig. 8), nine.

All the bulkheads must extend to the upper deck, except in awning-deck vessels, where all but the foremost may stop at the second deck. In these vessels the second deck is regarded as the upper one proper, and it might subside nearly to the water level without fatal results, for, owing to the continuous superstructure, the weatherly and navigable qualities would still be well maintained. The same remarks apply to shelter-deck vessels, but in these the collision bulkhead is not usually extended above the second deck. It is well that the collision bulkhead should be extended to the uppermost deck, for, should the bow be broken open by collision, the change of trim, the effect of the waves, and the pitching and forward movement of the vessel might cause the water to heap up or surge against it, high above the level of the sea without.

Art. 204. In sailing-ships, the collision bulkhead is the only one. Subdivision in sailing-ships, compared with that in steamers, would usually be less beneficial, for ships are not so liable to collision or mishap. They make long voyages in the open sea, out of the track of steamers; they rarely navigate the crowded waters in which most of the collisions and strandings occur, and when they do, they proceed cautiously, in charge of a tug-boat. Further, when a steamer is struck by collision, elsewhere than in way of the machinery, she may, if kept afloat by her bulkheads, proceed under steam to the nearest port, whereas a sailing-ship, so circumstanced,

may be quite unmanageable; and similarly in the case of stranding. Evidently, therefore, although subdivision may often prove useful in a steamer, its value in a sailing-ship would be so doubtful as not to warrant the resulting increased cost and the reduction in her efficiency as a cargo carrier.

Art. 205. In cargo vessels, **bulkheads are in many ways detrimental to commercial efficiency.** They increase the first cost of the hull, for, together with the bulkheads, extra hatchways, winches, pumps, etc., may be required for the additional holds; the weight of the hull is increased, reducing the dead-weight carrying power; cargo is less readily stowed in the smaller holes, and space is lost through broken stowage. In consequence of these disadvantages, and of the uncertainty of the bulkheads ever proving useful, it is natural that the owners of cargo vessels should prefer to fit as few as possible. In passenger vessels, however, safety under all circumstances should be the first consideration; for here, of course, mere insurance would not compensate for loss of life and the prestige of the line. Accordingly, modern passenger vessels are usually so thoroughly subdivided that even in the case of the most serious collision they would still float.

In **warships, subdivision** of the most perfect kind is essential, so that, although much damaged in action, there may still remain ample floating power. In large, modern battleships there may be more than 150 watertight compartments, small and large. Should it be necessary in time of war to supplement the navy by merchant vessels, it is clear that their very inferior subdivision might greatly detract from their usefulness. When, in 1875, the Admiralty drew up a list of merchant vessels whose subdivision was such as to make them eligible for this special service, it was found that there were only thirty British vessels available. The requirement, moreover, was the exceedingly moderate one of remaining afloat with any one compartment bilged, assuming half the space to be occupied by cargo. Subsequently, when shipowners became aware of the desirability of having their vessels on the *Admiralty list* (financially, a Government charter is, of course, very desirable), and to secure, for its own sake, the very desirable quality of safety, a more thorough subdivision became common. And Lloyd's rules now specify a more complete subdivision than formerly, especially in large vessels (see Plate 20).

When **damaged by collision**, the chances are greatly in favour of only one hold being bilged; but, **if the blow is struck on a bulkhead**, it may involve the hold on either side. In modern ocean-going passenger vessels (as also, very commonly, in Channel steamers) the latter condition is now always provided against. In some high-class vessels even three holds may be bilged without serious results; some of these vessels being subsidized by Government to act, when called upon, as armed transports. To enjoy equal immunity from foundering, all vessels, whatever their size, should have the same number of bulkheads; for size is only a relative quality, a small vessel being merely a large one on a reduced scale. In practice, however, an adherence to this principle would not be expedient. In a large vessel numerous bulkheads may cause comparatively little inconvenience, for the holds would still be of large size; indeed, they may here be an actual convenience, as a means of separating different classes of cargo, such as bulk grain or coal from general goods; so much, indeed, is this the case, that light, non-watertight bulkheads are sometimes fitted for this purpose only. Passenger vessels, which carry little or no cargo, may be still more thoroughly subdivided without detracting from their commercial qualities. It is evident, however, that to subdivide in the same manner a small cargo vessel, would not be expedient, for the holds

would be so small as seriously to interfere with the stowage. In the case of vessels engaged in the lumber trade, bulkheads so seriously interfere with the loading, stowing, and discharging of the long logs of timber, that Lloyd's Register permits of a smaller number, the transverse strength of the hull, which might be sacrificed by the omission of bulkheads, being retained by fitting deep web frames, or partial bulkheads. In such cases, while the vessel may have the highest class—**100 A1**—she is described in the Register book as intended for the timber trade, the actual number of bulkheads being stated.

Art. 206. With a view to legislation on the subdivision of merchant vessels, the Board of Trade, in 1890, appointed the "**Bulkhead Committee.**"[1] This body of experts was asked to consider what **rules of subdivision** might be made, such, that vessels conforming thereto would float in moderate weather with any two compartments in free communication with the seas; also, to what class of vessel these rules might apply, and what structural design would give to the bulkheads the necessary strength to withstand the bursting pressure of the water. To formulate any practicable scheme, that would apply generally to all vessels, is hardly feasible. The difficulty arises from the varying nature of a vessel's trade. Assuming certain conditions, it is a simple matter so to subdivide a ship that she may float with one or more compartments open to the sea, but in practice there is no fixity of conditions; on one voyage, when carrying a cargo of light, bulky goods, the subdivision might be ample; but on the next, when carrying a heavy, dense cargo, perhaps irregularly stowed, it might be quite insufficient. In the former case the bulkheads would have a potential value, but in the latter none at all; and in either case they might have a very prejudicial effect on the commercial efficiency of the ship. As already seen, to secure perfect immunity from foundering, the bulkheads must be so close together that should any two adjacent compartments be laid open to the sea, the vessel would still float, and this, moreover, when heavily laden with the densest cargo. To adopt universally such a high standard of subdivision would evidently be impracticable; in small vessels it would involve so many tiny holds, or so large a freeboard, that the commercial efficiency might be nil. These considerations are sufficient to explain the non-adoption of the suggested legislative measures.[2]

It will be instructive to notice some of the **conclusions of the Bulkhead Committee.** These, it should be observed, afford very valuable data, and in cases in which safe and complete subdivision is required, as in large high-class passenger vessels, they are often advantageously applied. The Committee proposed that a coal cargo might be taken as the standard one, and that when denser goods were carried, a suitable adjustment might be made by increasing the freeboard for the voyage. The minimum freeboard which they considered admissible in the bilged condition was that given by the margin-of-safety line, already noticed. They supplied, with their report, curve diagrams, by means of which, when the middle point of any bilged portion of the hull was known—whether one or more holds—its maximum length, compatible with the assumed margin-of-safety freeboard, could at once be noted. These curves were constructed from data obtained by experiments with a large floating model, minutely subdivided by bulkheads; the various cells were filled with coal, and, while keeping the margin-of-safety line always above water, any of them, as required, could be bilged.

Having regard to the very different duties of different types of vessels,

[1] See their report, published in Blue-book form.

[2] See Mr. Martell's paper on Bulkheads, *Trans. Institution of Naval Architects*, 1892.

and the greater degree of inconvenience which, as vessels decrease in size, the application of one plan of complete subdivision would cause, the Committee classified vessels under six heads, in which the requirements as to the number of bulkheads, or degree of immunity from foundering, became less and less stringent. They are as follows: (1) Large ocean passenger steamers and channel passenger steamers; to be so subdivided as to enjoy perfect immunity from foundering under the worst condition, namely, with any two holds bilged. (2) Smaller passenger steamers; to be so subdivided that they may remain afloat with any two fore-body holds, or any other, bilged. (3) Still smaller passenger steamers; so that they may remain afloat with the two foremost holds, or any other, bilged. (4) Yet smaller passenger steamers, and large passenger sailing-ships; so that they may remain afloat with the fore-peak and adjacent hold, or any other hold, bilged. (5) Cargo steamers and sailing-ships; so that they may remain afloat with any one hold bilged. (6) Smaller cargo steamers and sailing-ships; so that they may remain afloat with one hold in the fore body bilged. The requirements of the first grade would usually necessitate *eight* bulkheads; those of the second and third, *six;* of the fourth, *five;* of the fifth, *five* for steamers and *four* for sailing-ships; of the sixth, *four* for steamers and *three* for sailing-ships. It will be observed that the above requirements do not vary greatly from those of Lloyd's rules (Plate 20).

Art. 207. Lloyd's rules, as also the Merchant Shipping Act of 1854, require that screw steamers shall have a bulkhead near the stern—the **after-peak bulkhead**. Its purpose is to prevent the inrush of water which might result from fracture of the tail or propeller shaft, *i.e.* the aftermost length of shafting. As described in Art. 243, the watertightness of the hull, where the shaft passes through the stern, is secured by a stuffing box. This cannot be placed at the stern post, for, owing to the fineness of the hull, there would be insufficient space. In order that it may be accessible, and to provide, at the same time, a rigid bearing for the important propeller shaft, a tube of cast-iron—forming a journal—is introduced, the after end of which is fixed in the stern post, and the forward one to the peak bulkhead (see Fig. 8, Plate 29). The sea may enter the tube around the shaft, and is only kept back by the stuffing box which is placed at its forward end. The entire tube is thus enclosed in a watertight compartment (the after-peak), so that if, as a result of fracture of the tail shaft, it should break, the incoming water would be confined. It is, of course, possible that the damage might be so widespread as to involve the entire tube, including the watertight stuffing box and peak bulkhead supporting it; and so, to provide for this, the entire shaft is enclosed in a **watertight tunnel**, so that it, instead of the afterhold, would be flooded by the incoming water (Fig. 12, Plate 29, and Plates 109 and 110). The after end of the tunnel abuts upon the peak bulkhead, and the forward one on that of the engine room, from which it is entered through a watertight door. Sometimes, instead of a watertight tunnel, a **second peak bulkhead** is introduced a few feet before the first, making a second peak compartment; the tube terminates as before, at the first bulkhead, and its stuffing box is accessible by entering the second compartment, either from the deck or by a watertight door in the second bulkhead. The watertightness of the second bulkhead, where traversed by the shaft, is, of course, made good—like that of the engine room—by a stuffing-box. The efficiency of this arrangement depends much on the distance of the second bulkhead from the first, for if too near, and the shaft were badly ruptured or twisted, it also might be involved; the Board of Trade specifies a distance of twelve times the diameter of the shaft. Further considerations regarding the shaft tunnel will be found in Art. 244.

The purpose of the after-peak bulkhead is thus not to subdivide the ship, but to enclose, in a watertight compartment, the cast-iron shaft tube—always an element of danger. To do this, it is not essential that it should extend to the upper deck, it might terminate at a lower one, if this, abaft it, were made watertight like the top of a deep tank (see Fig. 6, Plate 20). This is sometimes done, but, as a rule, the bulkhead is extended to the upper deck (in many cases it is stepped forward or aft in the 'tween decks), the compartment abaft it—above the tank—forming a convenient store room or lazarette.

Art. 208. Bulkheads usually extend in one surface from keel to upper deck; in many cases, however, to suit cabin or machinery arrangements, the upper part is "**stepped**" forward or abaft of the lower (Figs. 3 and 5, Plate 20). As the deck between the two portions then forms a horizontal part of the bulkhead, it must be thoroughly watertight, its connection to the vessel's sides being made by one or other of the methods illustrated in Fig. 55. In some cases, where the crew are berthed in the 'tween decks, in front of the collision bulkhead, the 'tween deck portion of the latter may be placed well back from the stem (Fig. 5, Plate 20), the part below, to secure the largest hold space, being placed at the minimum distance ($\frac{1}{20}$th of the vessel's length) from the stem.

Art. 209. A bulkhead must have strength to withstand the maximum water pressure to which it may be exposed. To appreciate the essential features of its structural design, it will be well to notice, in the first place, the **general principles of water pressure.** The pressure on any submerged area, however disposed, is proportionate to its depth below the surface; that on a square foot 36 feet below the surface is one ton; if 18 feet below, it would be half a ton; at the surface, it is nil; the *mean pressure* acts, therefore, at half depth. The *average pressure* per square foot, over the *whole* surface, whatever its form, is that acting at its centre of gravity; its intensity, in tons per square foot, being the distance in feet of the centre of gravity below the water surface, divided by 35 (for salt water). The total pressure is, of course, the average pressure so obtained, multiplied by the total area. It follows that in similar bulkheads, the water pressure on one whose submerged part is twice the breadth and depth of another, would be eight times greater, for it has four times the area, and its centre of gravity is twice as far below the surface, *i.e.* the pressure varies as the cube of the ratio of the dimensions.

The centre of pressure is that point at which a single force would balance the total water pressure acting on a surface, *i.e.* it is the position of the resultant of all the different water pressures, which, as just seen, are zero at the surface, and increase regularly with each increase of depth. If a single horizontal strut or shore were placed against a rigid bulkhead at the centre of pressure, it alone could support it. The **position of the centre of pressure** varies with the shape of the bulkhead; in a rectangular one it is at two-thirds the depth from the top; in a triangular one, at half depth. It may be readily found for any area by graphic construction (Fig. 14, Plate 20); thus, if the water pressures on various horizontal layers or strips (*i.e.* the length of each strip multiplied by its depth below the surface) be set off as level lines or ordinates (O_1, O_2, O_3, etc.), the line or curve drawn through their ends—the curve of pressures—would, in the case of a rectangular bulkhead, be a straight line, forming with the bulkhead a triangle. The area of this triangle would represent the total fluid pressure, as also its vertical distribution, and so the centre of gravity of the area, situated at two-thirds its depth from the apex, would also be the centre of fluid pressure. If a curve of pressures be drawn for a triangular bulkhead

(Fig. 15), the enclosed figure will have a parabola for outline, and its centre of gravity (and the centre of pressure of the bulkhead) will be at half depth. As the bulkheads of a ship vary in shape from approximately a rectangle to a triangle, the position of the centre of pressure varies from two-thirds to one-half their depth from the water surface.

Art. 210. If a **bulkhead** were composed of a thin plated surface only, the water pressure, even if slight, would cause so great a **deflection** that the plating would suffer severe tension, tending to strain the various riveted joints and start the caulking. If an experimental strip of such a bulkhead be considered, the resistance it would offer would be of the kind given by a suspension chain, which, to resist a load without serious straining, must deflect largely from the straight (see Art. 110). Great deflection in bulkheads, however, is inadmissible, owing to its damaging effect on the riveting and caulking; it must, therefore, not resist like a chain, but like a beam, for this, according to its depth, may be so strong and stiff as to give a stout resistance without appreciable bending. This beam-like character is secured for the bulkheads by numerous **stiffening bars**; these may be regarded as forming a supporting framework for the thin plating as a mere watertight skin, but as they are firmly united thereto, each strip of plating and attached stiffening bar really forms a beam; under a deflecting pressure the plating may suffer compression, and, simultaneously, the remote edge of the stiffening bar, tension, or *vice versâ*. While giving the same total supporting effect to the bulkhead, the stiffeners might be few in number, but deep and strong, or numerous and slender. The stiffness of a rectangular beam varies as the cube of its depth, and so, theoretically, a few deep stiffening bars would be more efficient than a large number of smaller ones, *i.e.* the same total supporting effect would be secured with a less weight of material. But a full adherence to this principle would not be practicable, for, when under water pressure, the large areas of thin plating would bulge between the stiffeners, and, suffering severe tension, their riveted joints—single riveted in the usual way—would strain and leak. Evidently, therefore, the stiffening bars of a bulkhead, however strong individually, must be sufficiently close together to preclude serious straining of the thin plating between them.[1]

Four differently designed bulkheads are shown in Plates 22 and 23. Fig. 7, Plate 22, represents one designed strictly in accordance with **Lloyd's rules.** Here the **stiffening bars are disposed both vertically and horizontally.** The vertical are placed 2½ feet apart, and are of angle bar of the size of the vessel's frames; the horizontal are spaced 4 feet apart, and (excepting those of the collision bulkhead and others over 40 feet wide) are also of frame angle size; they are only fitted on the hold portion of the bulkhead, however, for in the 'tween decks the vertical stiffeners are so short as to give ample stiffness, and, moreover, any water pressure that might be experienced here would be small. In the earlier iron vessels the stiffening of the bulkheads was very inferior; there were no horizontal stiffeners, and the vertical were only of reverse-frame size. The thickness of the plating specified by Lloyd's rules varies from $\frac{5}{20}$ inch in a small vessel to $\frac{8}{20}$ inch in a large one; but when so thick as $\frac{7}{20}$ inch, the upper half of the bulkhead may be $\frac{1}{20}$ inch thinner than the lower.

It is not necessary that the stiffeners should be disposed both vertically and horizontally. The vertical are the more efficient, because they are the shorter, and because all—when of the same length—contribute the same

[1] An interesting study of the strength of bulkheads will be found in papers by Prof. Elgar and the late Mr. T. C. Read, *Trans. Institution of Naval Architects*, 1893 and 1886.

resistance to water pressure. In the case of the horizontal, while the uppermost, being near the surface, may suffer little stress, the lowest may be severely strained. If the vertical stiffeners were sufficiently strong, they alone might be perfectly capable of supporting the bulkhead, and in practice this single system is often adopted, and a bulkhead so designed is shown in Fig. 5, Plate 23. But although vertical stiffeners, if strong enough, may alone give ample strength against water pressure, a cross arrangement is superior in that the plating is better able to resist bulging tendencies, and the riveted seams are reinforced by the crossing of the bars; it also gives to the bulkhead perfect stiffness as a diaphragm; if, with vertical stiffeners only, the bulkhead should suffer severe lateral pressure in its own plane —through external pressure acting on the vessel's sides—it might yield transversely, by deflecting as a whole or buckling between the stiffeners, concertina-fashion.

As the total water pressure suffered by a bulkhead increases so rapidly as the cube of its dimensions (assuming the depth and breadth to vary together), it is clear that a system of stiffening sufficient for a small one might be quite inadequate for one of large size; in practice, therefore, when certain dimensions are exceeded, structural modifications are made. Thus, in a vessel requiring a lower deck, the depth of the 'midship bulkheads below this deck may only be about one-third of their breadth (Fig. 7. Plate 22), in which case the horizontal stiffeners would only be one-third as strong as the vertical ones (assuming both to be of the same scantlings), or one-twenty-seventh as stiff—*i.e.* under the *same* load the material would suffer three times the stress per square inch, and the stiffeners would deflect twenty-seven times as far from the straight. But, with a distributed load such as water pressure, the load or bending pressure increases with the length of the beam or stiffener, so that a horizontal stiffener (at mid-depth) would suffer three times the bending pressure of a vertical one, and as, owing to its three-times greater length, it can only support one-third the load of the latter, its strength would require to be increased nine times (in order that it may suffer no more stress per square inch than the vertical stiffeners). In practice the greater stress suffered by the horizontal stiffeners is provided against, for, when the breadth of a bulkhead exceeds 36 feet, a powerful **vertical web plate** or buttress is fitted at the centre, extending from the tank top to the lower deck (Fig. 7). This, in effect, divides the bulkhead into two of half area, and, as the horizontal stiffeners receive therefrom perfect support, they also are of half length, so that, apart from the 50 per cent. reduction of load, each half becomes twice as strong and eight times as stiff. In bulkheads over 40 feet broad, the capabilities of the two sets of stiffeners are still better proportioned by increasing the strength of the horizontal ones, by making them of bulb-angle bars (1 inch deeper than bulb-angle frame size). In bulkheads over 45 feet broad, two vertical webs are fitted, and in those over 55 feet, three.

In vessels in which the lowest deck is omitted in favour of hold beams or extra strong framing, it is evident that the bulkheads, being deprived of its supporting effect, would become virtually deeper, perhaps by 50 per cent. (Fig. 10, Plate 22). In such cases, therefore, a powerful **horizontal girder** is introduced (of the scantlings for semi-box, hold beams, Art. 128), either at the level of the suppressed deck, or lower down, where, being nearer the centre of pressure, its supporting effect is more required.

Under a distributed load, a beam of uniform section, with ends supported but free, is most severely strained, and would ultimately break, at the middle (Art. 573 onwards). As its strength is the same at each point of its length, much of that towards the ends might, therefore, be regarded as

useless, except in that it reduces the total deflection; and consequently, without diminishing its strength, it might be tapered in depth or thickness. As regards the **stiffening bars** of a bulkhead this is never done, for although to taper them might not reduce their strength, it would their stiffness, and it would evidently be inexpedient in other respects. The better plan is adopted of **fixing their ends by bracket plates**, for in this way their stiffness—as beams supporting a distributed load—is increased about five times, and their strength by about 50 per cent. (see Art. 575). Lloyd's rules require the ends of the horizontal stiffeners, when of bulb-angle section, to be fixed in this way, by brackets to the shell or hold stringers (Figs. 6 and 7, Plate 22). Besides increasing the efficiency of the stiffeners, such bracket connection is advantageous in holding the bulkhead square to the vessel's sides, and in better distributing its supporting effect. In the case of the vertical stiffeners, if the vessel has a double bottom, their lower ends are connected thereto by brackets, their upper ends being usually free (Fig. 4). The fixing of the lower ends is important, because, under water pressure, the greatest deflecting and straining tendency occurs low down, at the centre of pressure; so that while the upper part of the bulkhead may experience little stress, the lower may suffer much. If the bulkhead forms the end of a deep tank, the vertical stiffeners, like the horizontal, are made of bulb angle (or extra strong flanges), and both their top and bottom ends are fixed by brackets (Plates 24 and 25). With ordinary floors, the lower ends of the vertical stiffeners have no special connection; they are practically fixed in direction, however, because they extend right down to the frame, over the marginal plate of the bulkhead, which is held erect by the abutment of the ceiling planking and by the keelsons and intercostal plates (Fig. 9, Plate 21). Nevertheless, when great strength is required, as in deep tanks or the tanks of oil vessels, they are connected to intercostal plates fitted between the floors, or to bracket plates above them (see Figs. 10 to 12).

The **upper portion of a bulkhead**, lying between plated decks, is built distinct from the lower (Fig. 7, Plate 22). There are here no horizontal stiffeners, for the short vertical ones give ample strength against the more moderate water pressures to which the upper part of a bulkhead is liable. In the upper 'tween decks they are usually of the smaller reverse frame size, and in lower 'tween decks, of a size intermediate between frame and reverse frame. When there is a wood deck the planks abut on the bulkhead as shown in Figs. 1 to 4, Plate 21.

If a stiffening bar is not connected at the ends, it resembles a beam with ends supported but free. But even the support may be imperfect; thus, in the case shown in Figs. 6 and 7, Plate 21, in which the bulkhead plating and attached stiffeners are greatly deflected by an excessive pressure, the middle part of the stiffener would bend with the plating, for it is bound thereto by numerous rivets, but at its ends, where held only by the terminal rivets, it might be stiffer and stronger than they, and, refusing to bend, burst them and start away from the plating (deep flanges have been found to fail in the manner shown in Fig. 3, Plate 23). This tendency becomes more pronounced with powerful stiffeners, and so should be provided against, if not by a bracket connection, by a close grouping of the terminal rivets. Very commonly some of the excess of strength at the unconnected ends of stiffening bars is removed by tapering or sniping them, as shown in Fig. 1, Plate 21.

Art. 211. The **bulkheads of deck erections** are exposed to severe blows from the waves, in consequence of which they are not infrequently bent inwards; in some cases, when weakly constructed, they have collapsed,

the plating tearing along by the deck angle (Fig. 7, Plate 21). In these bulkheads the deck angles are usually single, and, to avoid the tendency of the plating to bend and tear along the line of rivet holes, the stiffening bars should not be cut short, but should overlap the angle (Fig. 5). The bulkhead forming the front of a bridge house must be strongly constructed to resist the bombarding effect of heavy seas; the stiffeners are, therefore, of bulb angle (Lloyd's rules require them to be 1 inch deeper than bulb-angle frames), and are connected at both ends by bracket plates (Fig. 8, Plate 21). In well-deck vessels the statutory freeboard is regulated to some extent by the efficiency of this bulkhead (Art. 58), and when supported by deep web plates, a reduction of 1 or 2 inches may be allowed. The thickness of the end bulkheads of deck erections is the same as that of their side plating.

Art. 212. It is now very usual to dispense with stiffening bars, by **flanging the plates**, for while the bulkhead is then equally strong and efficient, material and workmanship are saved. Some different arrangements are shown in Figs. 8 and 10, Plate 22; Fig. 5, Plate 23, and Plates 24 and 25. In Fig. 5, Plate 23, an arrangement is shown in which the vertical flanges are made so deep and strong as to dispense with the necessity for any other stiffening material. The plates are disposed vertically, and are of such breadth that their flanged edges are $2\frac{1}{2}$ feet apart; in the 'tween decks, however, they are often made twice as broad, in which case an intermediate stiffening angle is fitted between the flanged edges (Fig. 8, Plate 22). Comparing the stiffening effect of a simple flange (such as that shown in Fig. 10, Plate 22) and that of an angle bar, it is evident that, to be equally strong, the former must be deeper, for it is thinner, it has not a square rigid heel, and there is nothing to represent the material in the transverse flange of the bar. The necessary increase varies from $\frac{1}{2}$ inch in a $2\frac{1}{2}$-inch stiffener to $1\frac{1}{2}$ inches in a 7-inch one, or about 20 per cent. Although it has been proved by experiment (Art. 184), that, when a plate is subjected to crushing or compressive stress in its own plane, a flange connection (disposed at right angles to the crushing force) is inferior to that of an angle bar, it is not so when the flange acts as a stiffener against lateral bending pressures. In an **experiment made by Lloyd's Register** in 1892,[1] with two bulkhead plates, one of which was stiffened by an angle bar and the other by the flanged edge of the plate (about 1 inch deeper than the bar), the latter was found to be superior, for, when subjected to the same pressure, while it deflected only $\frac{1}{2}$ inch from the straight, the other deflected about 12 inches. This result was somewhat unexpected, in view of the apparently inferior stability of the flange. It demonstrated that the increase of $\frac{1}{20}$ inch, found necessary in the case of flanged floor plates and others subject to crushing pressures, is not required for flanged bulkheads. Where, as in Fig. 5, Plate 23, only vertical stiffeners are employed, consisting of an extra deep flange, the slender edge, projecting so far from the bulkhead, would be insufficiently stiff; accordingly, to obviate this, the excellent plan is adopted of flanging the edge of the flange, Z like, or back upon itself, like a channel bar (Fig. 4, Plate 83). When the depth of long flange stiffeners exceeds 12 inches, it becomes necessary to hold them square to their work, and this may be well done by fitting a face tie bar or an intercostal girder, in the manner shown in Figs. 1 and 5, Plate 24.

Art. 213. In order that a **bulkhead** may efficiently support the vessel's sides and maintain her transverse form, its connection therewith must be substantial and strong. Its supporting effect must be well

[1] Illustrated in *Engineering*, for October 14, 1892.

distributed, for if it were concentrated at one transverse line, the vessel's sides, elsewhere free and flexible, might suffer from the resulting local stress, so that the bulkhead, instead of being a source of strength, would be one of weakness. The **connection to the shell plating** is generally made with **double angles** of the usual frame size (Figs. 6 and 7, Plate 22); otherwise a **single large angle** may be employed, having flanges of double breadth, to take two rows of rivets (Figs. 4, 5, and 6, Plate 23).

A double-angle connection is stronger than a single one, for the rivets are in double shear; also, in whatever direction the plating may tend to deflect, it cannot, as with a single angle, so readily start the caulking and fold over or fracture where weakened by the line of frame rivet holes. Further, owing to the symmetry of the connection, the bulkhead is better held at fixed angle with the side. Nevertheless, if the bulkhead is thoroughly incorporated with the side, by bracket plates and by the side and deck stringers, it is evident that a single-angle connection may be quite sufficient.

To secure watertightness, the **rivets in the bulkhead shell angles** are spaced at **watertight pitch**; in the case of the shell flange this, of course, is only necessary in one or other of the two angles. A watertight spacing is usually rather less than five diameters of the rivet, which means that at least one-fifth or 20 per cent. of the entire sectional area of the shell plating is punched away in the transverse line of each bulkhead. Now, at ordinary frames the rivet pitch is 7 diameters, so that here only one-seventh of the plating is sacrificed; it follows, therefore, that at each bulkhead the sectional area or longitudinal strength of the shell is about $6\frac{1}{2}$ per cent. less than it is at the already weak lines of frame rivets. In practice a reinforcement is usually made by doubling the alternate strakes of shell across each bulkhead; *i.e.* by interposing between the bulkhead frame angles and the outer strakes of shell, instead of the usual narrow filling liners, a short plate, or "*bulkhead liner*." If it were only sought to recover the longitudinal strength of the shell, lost by the closer spacing of the frame rivets, the liners might be quite short; theoretically they need only be long enough to take one row of rivets clear of each frame angle, for, should the shell fracture through the closely spaced frame rivet holes, it would, before it were free, still have this outer row of liner rivets to shear. Formerly the liners were extended from the frame before the bulkhead to the one abaft it, but now they are usually made of the diamond shape shown in Fig. 14, Plate 21, the peculiar efficiency of which, as a connecting strap, is noticed in Art. 287. They are unnecessary, of course, in way of the double bottom, for here the strength of the hull is sufficient to discount any small weakness due to a transverse line of closely spaced rivet holes; and where joggled shell plating is adopted, bulkhead liners are usually dispensed with, for, as all strakes are then inside strakes, they would not be readily fitted; in such cases, instead of fitting liners, the thickness of the shell plate crossing the bulkheads may be slightly increased.

The **bulkheads are connected to the various decks** and to the inner bottom by **double angles** of reverse-frame size (Fig. 7, Plate 22), or by a **single large angle** having double-riveted flanges (Fig. 10). A specially strong connection to the tank top is desirable, because, when subjected to water pressure, it is the lower part of the bulkhead which suffers the most from the deflecting and straining forces. At the decks a strong connection is necessary as a substitute for the massive deck beam; a single small angle might not be in keeping with the capabilities of the bulkhead and deck, and, further, as the upper ends of the vertical stiffeners (both ends in the case of the 'tween-deck stiffeners) are usually unconnected,

the superior holding effect of double angles, or of a large single one, is particularly useful. In the case of a bulkhead stiffened by deep flanges, an excellent connection is sometimes secured to the deck by a single small deck angle and by a lug connection of the tops of the flanges (Fig. 2, Plate 23); the connection of a deep flange checks the tendency depicted in Fig. 3, and greatly improves its rigidity as a stiffener.

Art. 214. In a vessel not having a double bottom, the lower plate of the bulkhead is placed athwartships (Fig. 9, Plate 21). It is termed the "**bulkhead floor,**" but it is made deeper than the other floor plates, so that its upper edge may not foul the watertight collars around the keelsons. The assistance which the bulkheads give to the bottom of the hull, in resisting upheaving pressures, is noticed in Art. 72. It is the bulkhead floor that receives the brunt of the pressure, and, consequently, it is common to find, as a result of grounding, that where the ordinary floors and keelsons have merely bent slightly upwards, the bulkhead floor, held down by the upper part, has buckled sideways (Fig. 15); or, if it is shallow, and has only a single row of rivets in its upper edge, that these have shorn. It is, therefore, made of the same thickness as the ordinary floors, these being considerably thicker than bulkhead plating; and its upper landing edge is double riveted, this being useful in affording strength against the shearing tendency of grounding pressures, and the deflecting and straining effects to which—should the hold be flooded—the lower part of the bulkhead is more particularly liable. To stiffen the bulkhead floor against side buckling tendencies, the vertical stiffeners should, of course, extend right down to the frame angle (Fig. 9).

Art. 215. The necessity for absolute **watertightness** varies with the nature **of the bulkhead.** Those of a deep ballast tank must, of course, be absolutely watertight, for their primary duty, and one constantly exercised, is to confine water; were they to leak ever so little, contiguous cargo might be damaged. In the case of an ordinary bulkhead, so long as it is sufficiently strong, absolute watertightness is not so imperative, for it may never be called upon to confine water, and if, in an emergency, it were, any small leakage—controllable by the pumps—would, under the circumstances, be a small inconvenience. In the case of a deep tank, the bulkheads must be designed and constructed with a special degree of care, so that there may be no tendency to even incipient straining, with its accompanying effect of leakiness. As already noticed, they are particularly well stiffened; in tanks of great depth the seams are double riveted, and the efficiency of all watertight work is carefully attended to. The structural arrangement of two deep tanks of modern design is shown in Plates 24 and 25. In the case of oil-tank bulkheads, as these are usually deeper, and as oil-tightness is more difficult to secure than watertightness, even greater strength has to be provided and more care taken to secure perfect workmanship (see Art. 54). The structural details of a large oil tank are shown in Plate 26.

The **collision and after-peak bulkheads** are exceptional; the chance of their being called upon to exclude water is greater than with other bulkheads, and so more care is usually given to the details of their design. **Their watertightness is tested,** in new vessels, by filling the peak compartments with water; that of the others, if tested at all, is only tested by hose. The collision bulkhead, if the bow is broken open by collision, may be exposed to the waves; and as it has the distinctive duty of holding the sides against the pronounced panting tendency of this region, its strength, horizontally, is specially studied by making the horizontal stiffeners of bulb angle, and bracketing them to the side (Plate 10);

in other bulkheads this is only required when their breadth exceeds 40 feet.

Art. 216. Bulkheads may be plated vertically or horizontally. The former is the more usual plan, for horizontal seams involve tapered liners (or the tapering of the plate corners) between the frame angles, and they may interfere with the lugs or watertight collars of the side stringers; when a horizontal disposition is adopted, however, this inconvenience may be avoided by fitting the marginal plates vertically. When the plate edges are flanged to form stiffeners, the seams are, of course, vertical. To reduce the riveting, the stiffening bars are sometimes placed on the seams of the plating; but this is an inferior arrangement, for it involves three-ply riveting. In the case of 'tween-deck bulkheads, if not flanged, the horizontal disposition is the more common (Fig. 7, Plate 22), for it avoids numerous liners (or the tapering of the plate corners) between the deck angles, and as there is only one horizontal seam to caulk, and fewer plates to fit and rivet, the workmanship is reduced; this, indeed, is the governing consideration in arranging all details of ship construction.

Art. 217. Watertight **longitudinal bulkheads** are rarely adopted in ordinary merchant vessels. They are, sometimes, in the engine room of large twin screws, the port and starboard engine being separated by a centre-line bulkhead (Fig. 2, Plate 28). In large high-speed vessels the numerous boilers are usually divided into two or more groups, separated by watertight transverse bulkheads, so that, however damaged by collision, boiler power may still be available (Figs. 1 and 2); and, of course, a similar assurance is equally desirable for the engines. As such an engine-room bulkhead is short, it gives little useful structural strength to the hull, except in that, by tying together the decks and bottom, it gives rigidity against the vibrating effect of the engines. In some large, high-speed passenger vessels the central bulkhead is carried through both the engine and boiler space, and as these together may extend over almost half the vessel's length, it may confer considerable longitudinal strength to the hull. To give useful assistance, however, it must be connected to continuous deck plating, and be so strongly constructed as to stand erect and take its share of the work; and its ends should be tapered gradually down to the keel, for if the bulkhead stopped abruptly it might be a source of weakness rather than of strength.

As a means of subdividing the hull into watertight compartments, longitudinal bulkheads cannot be favourably regarded, for, should a large compartment on one side be flooded, the vessel might take a serious list—a dangerous matter in a deep-loading cargo vessel. In warships there are numerous longitudinal bulkheads (Plate 113); here, however, together with a central one, there are usually one or two close to the side; and as all compartments are small, the chance of a serious list through damage in action is small, and, moreover, every facility is provided for correcting it by flooding compartments on the opposite side. It is sometimes urged in favour of longitudinal bulkheads that their integrity would not be prejudicel by broadside collision; when fitted as in warships, as an inner skin, this is an important advantage, but with only a centre-line and transverse bulkheads, a blow struck on one of the latter might be a very serious matter.

In merchant vessels there may be numerous longitudinal bulkheads, but they are not watertight. There are the side coal-bunker bulkheads (Figs. 4, 5 and 6, Plate 27, and Plate 109), grain bulkheads (Figs. 27 to 29, Plate 13), and the wash or divisional bulkheads of deep ballast tanks (Plates 24 and 25). The coal-bunker bulkheads, as noticed below, are of light construction.

Grain bulkheads must be strongly constructed, for they take the place of pillars (see Art. 148). Wash bulkheads, such as are required in deep ballast tanks, are not watertight; they must be exceptionally strong, however, for not only do they take the place of the pillars, but they are liable to severe pressure, and blows from moving water. Vessels which carry oil in bulk are provided with a continuous, oil-tight, centre-line bulkhead (Figs. 10 and 11, Plate 26); like the others, this one must be exceptionally strong, for it may have to withstand a full pressure of oil, and perhaps an occasional bombardment through incomplete filling of the tanks. Other matters in connection with oil tanks are noticed in Arts. 54 and 449, and the general construction of the bulkheads is shown in Figs. 9 to 11, Plate 26.

Art. 218. Coal bunkers are considered in Art. 231. As their **bulkheads** have only the minor duty of confining coal, they may be of slender construction. In the case of a large bulkhead the pressure from the coal may be considerable, especially that of a side bunker, which, when inclined with the rolling of the ship, may take some of the weight of the coal; but even then a light construction may suffice, for when of large area they are stayed to the vessel's side or to the opposite bulkhead (Fig. 5, Plate 8; Fig. 13, Plate 21; and Fig. 5, Plate 27). Being slender and yielding, such bulkheads confer little or no strength to the hull. In the case of the side bunker bulkheads alongside of the machinery space, where numerous deck beams are severed, they may help to support the marginal part of the deck, so much so that if strongly constructed they may permit of the suppression of a row of side pillars (Figs. 4 and 6, Plate 27). Often, however, to secure a capacious bunker, the upper part of such bulkheads is sloped or curved outward over the boiler (Figs. 3 and 5), when, of course, they give practically no support to the deck. In warships, all parts, however subsidiary, are so designed as not only to serve their primary purpose, but to co-operate in the general strength of the hull. Coal-bunker bulkheads are, therefore, built like the others, so that while serving as watertight partitions they may also strengthen the contiguous structure.

The scantlings of ordinary coal bulkheads do not vary greatly, for they are decided not so much by the question of strength as by that of endurance against corrosion, which, as noticed in Art. 463, is particularly rapid in the coal bunkers. The plating is usually $\frac{5}{16}$ inch thick. It may be of steel or iron; iron is often preferred on account of its slower rate of corrosion. Unless frequently coated, the bunker bulkheads do not last many years; it is common to find them corroded through in large holes, and repaired in a rough-and-ready fashion with bolted patches of sheet iron. It is evidently well, therefore, to provide a margin of thickness; in some exceptional cases the plates are made $\frac{1}{2}$ inch thick. The stiffening bars vary in size from $2\frac{1}{2}$ by $2\frac{1}{2}$, to 3 by 4 inches, and are spaced from 2 to 4 feet apart; they are usually placed on the vertical seams of the plating. When the bulkhead is required to take the place of pillars, it is stiffened as described in Art. 148 for grain bulkheads. The stiffeners should be considerably thicker than the plating, for they are particularly liable to wear and tear, due to the circumstance that the projecting flange offers two surfaces to corrosion, and is exposed to the scarifying action of the coal. In view of this, it is evident that the flange system of stiffening is not suitable for bunker bulkheads. The stiffeners are usually placed vertically, for when horizontal they form a lodgment for coal, and are exposed to blows from falling masses. As already seen, bunker bulkheads of large area are stayed horizontally to the vessel's side; if required to be self-supporting the scantlings must be increased. The stays are usually of angle bar, connected to the stiffeners and side stringers by bracket plates

(see Fig. 5, Plate 27). They are particularly exposed to wear and tear; the battering effect of falling masses bends or breaks them, and, being subject to the scarifying action of the coal, they quickly waste away. They should, therefore, be substantial; if of angle bar, the heel should point upwards, so as to present an enduring edge, capable of splitting up falling lumps of coal (see Fig. 13, Plate 21). They should not be placed directly under the coaling hatchways, for they cannot long endure the continued battering effect of the coal thrown from above (Art. 463).

The transverse bulkheads of cross coal bunkers are usually of stronger construction than those of the side, for they are generally of larger area, and cannot be so extensively stayed. The plating may be no thicker, but the stiffening bars are usually stronger. They are connected to the vessel's side by a single frame angle, and as the shell rivets are spaced at the usual wide pitch, special liners are not required. They must be connected to each deck by large angles, so as to secure the full strength of a deck beam; often, however, they are merely riveted to the side of a deck beam. When fitted intermediately in a long machinery space, four large angles or two channel bars are usually fitted at each deck level, to give the strengthening effect of the strong I-section beams described in Art. 129.

Coal-bunker bulkheads should be so tight as not to pass coal dust; in ordinary cases the joints are made sufficiently tight by the riveting. In high-class work they are caulked; watertightness is not aimed at, for where beams, etc., pierce the plating, the apertures are only closed by plate collars, more or less accurately fitted (Art. 329). Fore-and-aft bunker bulkheads are connected to the tank top by a single angle, which, if the bunker is long, is severed at places so that water, accumulating on the central portion of the tank top (leakage from the boiler or engines), may pass through the bunker to the side gutters, the ceiling planking within being raised on bearers so that the water may pass under it. A bunker at the side of the engine room is sometimes built with an independent bottom (partial or complete), raised a couple of feet above the top tank, so that pipes may be led underneath it, or to provide access to sea cocks on the bilge. With ordinary floors a side-bunker bulkhead may connect to the bilge keelson, otherwise its lower marginal angle merely connects to the reverse bars on the upper edges of the floors, the enclosure of the bunker being completed by the ceiling planking within (Fig. 13, Plate 21). In large vessels, where superior strength is desired, the bulkhead stiffeners are bracketed to the floors or tank top (Fig. 5, Plate 8). The upper margin of a side bunker bulkhead passes up and connects to the deck plating between the beams, plate collars being fitted around the latter. In small vessels, where there is only a wood deck over the side bunkers, short angles may be bolted thereto to take the bulkhead; but it is better to fit a continuous angle above the beams, notching its vertical flange so that it may project downwards between them, and take the bulkhead plating. Coal-bunker doors and other matters in this connection will be found in Art. 413.

CHAPTER XVI.

Art. 219. Elevated **deck openings** are required **over the engine and boilers.** That over the engine is necessary for lighting and ventilating, and is provided with a skylight (Fig. 6, Plate 27; Fig. 2, Plate 29; Fig. 1, Plate 31; Fig. 4, P. 109). That over the boilers, usually termed the "*fiddley opening*," is required to pass the funnel, and provide ventilation for the hot stokehold; and as it must be permanently open, it is covered only with an iron grating (Fig. 3, Plate 27, and Plate 109). These openings must be elevated, so that water sweeping the deck may not pass through them below. This is effected by the *machinery casing*. In a small one-deck vessel this is practically a deck house built around the openings, so that the latter, being elevated to its roof, are secured from the sea water which may roll on board. It also serves as a companionway, or entrance to the machinery space, for which purpose doors are provided in its sides. In some of the earlier steamers the necessity for elevating the machinery openings was not sufficiently realized; the engine-room skylight sat upon the deck, and the fiddley was formed like an ordinary cargo hatchway, with low coamings (Fig. 1A, Plate 26); consequently, when heavy seas swept the deck, the engine-room skylight was sometimes stove in, volumes of water passed below, and, extinguishing the fires, sometimes caused the loss of the ship (see Art. 417).

The **security given by the casing** depends much upon its height above the weather deck and sea level. In low-freeboard vessels Lloyd's rules require it to stand at least 7 feet above the deck; and in awning-deck vessels, where the upper deck is well above water and out of the range of the waves, $4\frac{1}{2}$ feet. In practically all but awning and shelter-deck vessels there is a 'midship bridge house (Figs. 1 to 8, Plate 26, and Figs. 1 and 2, Plate 29), *i.e.* the sides of the ship are carried up and decked over; here, therefore, the casing is enclosed, so that the bridge deck is, for it, the weather deck; in such cases the openings, being already elevated, need only be raised some 2 or 3 feet above the bridge deck. If, in a low-freeboard vessel, there were no bridge house, the casing, being exposed to the violence of the waves, would have to be specially strongly constructed, and in heavy weather access to the machinery space would be attended with danger. Many of the earlier vessels were so designed, but the advantage of a bridge house was soon recognized, for not only does it increase the vessel's safety in heavy weather, but provides additional cargo or coal-bunker space and accommodation for the officers and crew.

The engine and boilers may occupy but a small portion of the vessel's interior between the machinery bulkheads. In most vessels there is room on either side for a coal bunker (see Fig. 5, Plate 8, and Plates 27 and 109). In high-powered vessels having two or more decks, although the engine and boilers may occupy the entire width of the lower hold, they may take up very little of the space above, in the 'tween decks; here, therefore, the space on either side is cut off by a **downward extension of**

the casing, which forms a sort of shaft or trunk (Fig. 5, Plate 8, Plate 27; Fig. 1, Plate 31; and Fig. 11, Plate 76). It may extend downwards to the second deck in unbroken width, but if there is a third deck, the lower part must usually be stepped or sloped outwards, to clear the engine and boilers (see Fig. 3, Plate 27). If there is a side-bunker bulkhead below the lowest deck, it may be regarded as the ultimate extension of the casing. The 'tween-deck spaces on either side of the casings are generally used as coal bunkers; in passenger vessels, however, the upper, or all of them, may be appropriated for passengers, for in this respect it is valuable space, because it is amidships where the vessel's movement is less felt, and because it is contiguous to the ship's side, where daylight may be secured by sidelights.

The shaft formed by the machinery casings is usually termed the "*light and air space*."[1] The portion above the level of the engine cylinders, besides admitting light and air to what would otherwise be a dark and hot engine room, is required to permit of the cylinder covers and pistons being lifted for examination and overhaul (Fig. 4, Plate 109). Its width in way of the cylinders must be such as will give access around them, and allow daylight to be shed below. In twin-screw steamers there are two rows of cylinders, and so, to embrace both, the casing must be extra wide (see Fig. 1, Plate 31). The lowest deck, to clear the twin engines, may have to be entirely suppressed, or very much cut away. Those decks which are well above the cylinders may overhang them, so long as hoisting gear may be plumbed over their centres for lifting the covers and pistons. In rare cases, when the port and starboard engines are partitioned off by a centre-line bulkhead, separate casings are provided for each engine room.

Art. 220. In ordinary vessels the **casing extends continuously from end to end of the machinery space**, but the openings in the upper deck are not necessarily so extensive; that over the engine need be little longer than the row of cylinders, and that over the boilers need only be long enough to pass the funnel, and leave a clear opening over the stokehold (Plates 108, 109 and 110). In most cargo vessels, however, an additional opening is required between the engine and boilers, to form a *trunk hatchway* for the side bunkers (Fig 1, Plate 29, and Plate 109). It follows, therefore, that according to the arrangement of the engine and boilers there may be unoccupied spaces within the casing. At these places strong through beams are introduced at each deck, and when plated over between the casing walls, the small deck areas so formed may afford convenient locations for the galley or donkey boiler, whose chimneys, being near the main funnel, may join therewith, and thus obtain a good draught. In large passenger vessels the machinery casings—or extensions of them—may provide accommodation for several galleys, sculleries, and pantries, the space over the boilers and contiguous to the hot funnel being used as a "drying room" for the stewards' linen or the washings of the crew and emigrants (Plate 108). The 'midship portion of the 'tween decks is the most suitable for passenger accommodation, for there is here less pitching movement and vibration. In most vessels it is occupied or obstructed by the machinery casings, but in large, modern, passenger vessels the boilers are usually divided into two or three groups, the hold between being used as a large coal bunker, and the 'midship deck areas above appropriated for cabins and saloons (Figs. 1 and 2, Plate 28).

Art. 221. The **width of the casing** or deck opening over the boilers depends on several circumstances. It must be large enough to pass the funnel and a large ventilator on either side, and give an ample

[1] Properly speaking, the term only applies to the portion above the upper deck.

area of fiddley opening for free ventilation of the stokehold (Plate 109, and Fig. 4, Plate 31); if too small the boiler room might become unbearably hot (Art. 451). Often it is decided by the space required between its walls for the galley or donkey boiler, or by the deck area required on either side, so that this may be sufficiently wide for side cabins and a passageway. Or it may be governed by the question of tonnage, so that the internal volume of the light and air space, when added to that of the engine and boiler room, may bring the total within the necessary limits (13 and 20 per cent. of the gross tons) for the securing of a maximum deduction, or "*engine-room allowance.*"[1]

The **engines and boilers** are put on board after the launch. They are **lowered into place** by a large crane or derrick, and, of course, foresight must be exercised that the deck openings may be sufficiently large to let them pass. To admit a large boiler, the casing and deck opening may require to be very wide, and to avoid this, therefore, one side of the casing and a portion of the deck contiguous thereto are not riveted up until it is shipped. The inner ends of those half-beams which would interfere with the passage of the boiler are cut, and are afterwards jointed with riveted fish plates. Those of the upper deck may not require to be cut, but at the lower deck, where, in lowering the last boiler, it may have to be swung to one side to clear the upper part of one already in place below, a considerable portion of the half-beams may have to be temporarily removed (see Fig. 5, Plate 27). Where strong beams pass over the boilers, they also may have to be jointed so that the portion within the casing may be temporarily removed. All plates, beams, etc., which must be removed to admit the boilers, should be so arranged, of suitable lengths, that as little as possible of the structure need be disturbed. As the largest single part of the engine is comparatively small, there is usually ample room for its passage between the casing walls; here, therefore, only the casing roof need be left unfinished.

Art. 222. On the top of the casing, over the **engine**, there is a large **skylight**—in some vessels there are two. The casing top is plated over, but the skylight usually occupies almost the entire width, leaving only a strip of plating on either side (see Fig. 6, Plate 27, and Fig 2, Plate 29). If there is a bridge deck, the roof of the casing may be built flush therewith, in which case the skylight is elevated on a coaming plate, at least 2 feet high. Otherwise the whole roof may be raised above the bridge deck (see Fig. 2, Plate 29). The skylight must be strong, so that in heavy weather it may not be stove in by flying masses of water. Formerly it was made of teak wood, but now it is practically always built of thin steel plates, for it is then stronger, cheaper, and more durable. It has large hinged sashes, provided with glass bull's eyes; but when situated well above the water, large panes of thick glass, protected by gratings, are sometimes used. In vessels which trade in the tropics, to secure better ventilation of the engine room, a large dome-shaped grating, or cage, may be substituted for a skylight; it is covered from the sun by an awning, and in heavy weather by tarpaulins, arranged to wind up on rollers. A small wood skylight is usually fitted on the top of the casing over the galley.

The **fiddley openings** are often placed at a higher level than the engine skylight, so that they may be kept open in all but the heaviest weather. If there is a bridge deck they must be at least 2 feet above it, but very commonly they are raised to about 7 feet (Fig. 5, Plate 27). In large passenger vessels the casing is carried above the highest flying

[1] An excellent description of the tonnage laws and various interesting matters in this connection will be found in Sir W. H. White's "*Manual of Naval Architecture.*"

deck, so that the passengers may not be inconvenienced by the smoke, dust, or smells which pass up from the stokeholds. In some cases, the better to shelter and hide the fiddley openings, the sides of the casing are carried up above the roof, to form a sort of bulwark around them. The fiddley openings themselves are covered with **gratings.** In heavy weather, when seas break over the ship, it may be necessary to cover the gratings, for although this may result in an uncomfortably hot stokehold, sufficient air for the furnaces may still be supplied through the large cowl ventilators. For this purpose, hinged **sheet-iron storm covers** are sometimes provided, otherwise provision is made for closing only by tarpaulins. Whether or not it may ever be necessary to close them depends on the type of vessel and her particular trade. Around the openings there should be a coaming or angle-bar ledge, and side cleats or jackstays for battening down a tarpaulin.

Art. 223. In order **to fill the bunkers** in the side 'tween decks, a small **hatchway** is usually placed in the roof of the casing over the boilers or between them and the engine (see Fig. 5, Plate 27, and Fig. 1, Plate 29, and Plate 109). This may be described as a sort of trunk or shaft, whose sides open into the upper or lower side bunkers, and whose bottom is shaped like an inverted V, or "**saddle,**" which formation diverts the coal sideways into the bunkers and gives clearance below it, over the boilers or engine. The wear and tear of the saddle and contiguous side plates is often very great, due to corrosion (accelerated by heat from the boilers) and the attrition of the coal; they should, therefore, be thick, not less than $\frac{3}{8}$ inch.

Art. 224. The **machinery casing,** if it does not take the place of side pillars, is **of slender construction;** of plating about $\frac{1}{4}$ inch thick, stiffened by vertical angle bars, about 3 by $2\frac{1}{2}$ by $\frac{5}{16}$ inches, spaced 30 inches apart, or sometimes the plates are flanged. When not enclosed by a bridge house, it must be more substantial. As noticed in Art. 157, the casing may have the important duty of supporting the ends of the numerous half-beams. When it thus takes the place of pillars it is made $\frac{5}{16}$ inch thick, the stiffeners being of reverse-frame size, placed 2 feet apart, and at each deck there is a stout coaming plate, from $\frac{2}{20}$ to $\frac{4}{20}$ inch thicker than the remainder (see Figs. 1, 3, 5, and 6, Plate 27). In large vessels the coaming may be particularly substantial, so as to form a powerful fore-and-aft beam or girder. In order that the half-beams may derive proper support from the coaming, their ends should evidently connect thereto; formerly, in the case of the lower deck, where the casing was not continued below, or was stepped outwards, they did not always do so, the coaming merely sitting on the deck plating, and the beam ends, for the sake of appearance, being rounded off, as shown in Fig. 2, Plate 29. This, of course, is a faulty construction, for were the beams called upon to exercise their full capabilities, their ends, upheld only by one or two terminal rivets through the deck plating, would derive little support from the contiguous coaming, and might burst away from the deck plating. The coaming should stand at least 18 inches above the weather deck, and when there are doorways in the side of the casing, their sills should also be at this height, to avoid the chance of deck water passing below.

The **stiffening bars** are usually placed **within the casing,** for if outside they would interfere with the passageways or cabins, or, if in a side coal bunker, they would be exposed to the abnormal corrosion which prevails in this place. When the sides of the casing are insulated, as in passenger vessels and cattle-boats, they are usually placed outside, so as to provide the necessary space and attachment for the insulating material

(Fig. 11, Plate 76). When within the casing, they very commonly stop short at each coaming; it is better, however, that they should extend in one length from top to bottom of the casing wall, for they then stiffen the coamings and reinforce the weak line formed by the row of rivets connecting the latter to the thin casing plates (Fig. 6, Plate 27). When the stiffeners are formed by flanging the edges of the plates, they are defective in this respect.

The casing plates between the coamings are usually fitted lengthwise, in a single breadth. The vertical seams are lapped, and, to save rivets, are usually placed on the stiffeners. In passenger vessels they may be butt-jointed, and, if a flush surface is desired, the connecting straps may be formed by a large-flanged angle or tee-bar stiffener within; or if the appearance of panelling is desired, the straps may be placed outside, to form pilasters. The casing may be of steel or iron, usually it is of steel, for longer and wider plates are procurable in this material, and at a less cost than iron.

The **roof of the casing,** between and around the openings and funnel, is supported by light angle beams, bracketed to the vertical stiffeners (Figs. 5 and 6, Plate 27), but as the areas of plating are small, and as they are stiffened by the coamings around the openings, few are required. The strip of plating around the engine skylight is usually supported by bracket plates. As the top plating is exposed to the weather, and is always hot, it is readily affected by corrosion; it should, therefore, be of substantial thickness, at least $\frac{3}{8}$ inch. All rivets should be closely pitched, and all exposed joints should be caulked to avoid the bursting effect of corrosion, here specially pronounced (see Art. 466).

If the **casing** is long, its **sides** should be **connected by divisional bulkheads,** such as the partitions of the galley, donkey-boiler room, or trunk coaling hatchway. If only united by the roof, and a few isolated strong beams, the whole box-like structure might strain or sway from side to side. When united by plated divisions, it not only becomes strong in itself, but checks vertical straining tendencies in the decks alongside; and, where exposed to the weather, is better able to resist blows from the waves. Deck beams which abut on the casing coaming plate are connected thereto by an angle lug; if the beams are on alternate frames, by a pair of lugs, When of angle or bulb-angle section, they are sometimes boxed at the end, *i.e.* the web is turned round as shown in Fig. 1B, Plate 27, thus dispensing with a lug. Where the beams run through, plate collars are neatly fitted around them (Fig. 1A). Sometimes, in way of the engine-room skylight, the bridge-deck beams are not cut, but run right through. When the casing top is flush with a wood bridge deck, the planks must, of course, stop at the side of the casing, for on the top they could not endure the heat (Fig. 2, Plate 29).

Art. 225. In large passenger vessels portions of the machinery **casings** are usually **built with double walls,** from 1 to 2 feet apart, so that the shaft so formed may serve **for lighting and ventilating** the passenger accommodation in the 'tween decks below (Fig. 5, Plate 8; Plates 107 and 108). Usually the inner wall is regarded as the casing proper, the outer being less substantial, and when the decks are plated, the plating usually stops at the outer wall, if extended to the inner, it must be pierced with large holes to admit the necessary light and air. Although the deck plating may stop at the outer wall, the beams are run through to connect to the strong coaming plate of the inner one; but sometimes they also stop at the outer, and in order that this may form a sufficiently strong fore-and-aft girder, it is thickened and connected at intervals to the inner coaming by diaphragm plates (Fig. 5, Plate 8). The upper part of these lighting and

ventilating shafts terminates above the weather deck, with a sloping skylight top, fixed or hinged, having glazed flaps, bull eyes, or mushroom ventilators. They form convenient ventilators for water-closets in the 'tween decks, and when used as such they should, of course, be carried well above the passengers' promenade deck. Similar lighting and ventilating shafts may be provided at other parts of the ship, leading down to the various 'tween-deck passenger spaces and standing well above the weather deck (see Fig. 21, Plate 75). When they are required to serve more than one 'tween deck space, they may be built one within another, each stopping at a different deck.

Art. 226. A **trunk hatchway** is one in which the coaming plates of the different decks are united by a casing or trunk. They are required in passenger vessels in order that when a hatchway is opened to work the cargo in the hold, the passenger accommodation in the 'tween decks may be unaffected by the operation (Fig. 8, Plate 20, and Plate 108. When at sea, these trunk hatchways may form convenient companion ways, doors being fitted in the 'tween-deck portion, and ladders leading up to a portable companion on the upper hatchway. They may also be employed for coaling the lower bunkers through 'tween-deck cargo spaces or passenger accommodation.

Art. 227. Deck houses may be of wood or steel; but often they are composite, having a coaming plate, stiffening frames, and beams of steel, to which the woodwork is affixed. The side houses under a bridge or forecastle deck are usually of steel or iron. The actual details of their construction vary considerably; the usual plan is to fit a sort of coaming above as well as below, in short lengths between the beams and projecting below them sufficiently to take the side plating. It is connected to the deck by short angles between the beams, and, to cover the irregular notch made to pass the latter, plate collars are neatly fitted around them (Fig. 1A, Plate 27). A plate collar provides no attachment, and so, if the beams are large, angle collars should be fitted. Where a large number of similar collars are required, they are sometimes made of cast steel, from a pattern fitted to the particular beam section. If for a bulb beam, they are made in halves, so that they may be shipped over the bulb. In vessels which trade in the tropics, and in which ample ventilation is, therefore, essential, the fore-and-aft bulkheads of the side houses under deck erections terminate at the lower edge of the beams, the spaces between being provided with gratings or hinged flaps.

CHAPTER XVII.

Art. 228. The **machinery and coal bunkers** are situated **amidships**, in practically all vessels except small coasting boats and oil steamers (see Figs. 1 to 8, Plate 20). This disposition is advantageous in that, during a voyage, the consumption of coal does not result in a change of trim; if the machinery were **at the stern**, and the vessel started on her voyage fully loaded and on even keel, the consumption of coal from the sternward bunkers would cause a constantly increasing trim by the head. If it were a short voyage, the change of trim would be so small as to be unimportant, and might be provided against by starting on the voyage with a slight trim by the stern. In the early steamers it was hardly practicable to place the machinery at the stern, for, owing to their less efficient engines and low-pressure boilers, they required much more coal; they burned over 2 lbs. per horse power per hour, whereas a modern vessel only consumes from $1\frac{1}{2}$ to $1\frac{3}{4}$ lbs. Another important objection to the sternward position is the pronounced trim by the stern which prevails in the light condition. As noticed in Art. 108, when a vessel's fore-foot is near the surface, she is not only difficult to navigate against head seas, but may suffer damage from impact with the waves. To secure, in a light ship, the utmost immersion and stability, all ballast tanks are filled; and, in a large one whose machinery and coal are at the stern, the heavy weight of water in the fore peak, and of machinery and coals at the stern, may result in severe longitudinal and local stresses. In this respect, however, the 'midship position is also disadvantageous, for in a large vessel, when many hundreds (or thousands) of tons of coal have been consumed from 'midships, the hull, heavily laden towards the ends, may suffer hogging stresses of a most crucial kind; it is when so circumstanced that the structure of a large vessel is most severely tried (Art. 6).

In the case of very **small vessels** the **sternward position** may be convenient in many ways. The disadvantages above mentioned are less pronounced, because, making short voyages, they carry and consume little coal; and any small alteration of the trim may be corrected, if necessary, by the trimming tanks. The circumstance that, when running light, the bow may be almost out of the water, and so, when head seas are encountered, result in objectionable wave-pounding action at the fore-foot, is, in these small vessels, more than counterbalanced by the superior propelling efficiency and speed which follow from the thorough submersion of the propeller and the small displacement. Further, their first cost and subsequent efficiency is improved by the sternward position; for, with the machinery amidships, there would be one more bulkhead, a long line of shafting, and a watertight tunnel; the weight of hull would be greater, reducing the carrying power, and there would be two small holds instead of one large one (see Figs. 1 and 2, Plate 20). In a small vessel, shortness in the holds may preclude her from carrying certain cargoes, such as rails

and timber; and it may cause broken stowage, and additional expense and loss of time in the frequent loading and discharging operations. The sternward position is also advantageous as regards the fixture of the engine in the hull, for, owing to the narrow, V-form of the vessel's sections, powerful engine seating may be constructed with a minimum weight of material. In **oil steamers** the sternward position is particularly suitable, for as any or all of the oil tanks may be used for water ballast, the trim and draught, when light, is capable of perfect adjustment. The avoidance of one machinery bulkhead is here an important matter, for, as noticed in Art. 54, these must be built as cofferdams. Also, when there is a tunnel, it must be strongly and carefully constructed, so as to secure absolute oil-tightness; it must be shut off from the engine room, and access provided by oil-tight trunkways from the upper deck; further, mechanical ventilation must be available, as a precaution against the dangerous consequence of oil leakage. In some early oil vessels the tunnel was built with a double shell; but this was found to be unsuitable, owing to the difficulty of access to the confined intermediate space, and the accumulation within it of inflammable gas.

Art. 229. The **arrangement of the machinery space** varies greatly in different vessels, particularly as regards the boilers and coal bunkers. It depends on the character of the vessel, whether a slow cargo boat or a high-speed passenger vessel, the type of the engine, and the number, size, and type of the boilers. In a cargo vessel it is always endeavoured to reduce the length of the machinery space, by a compact arrangement of the engines and boilers, for then, of course, the cargo holds may be the more capacious; but this, again, is oftened governed by the question of tonnage.

There are two distinct types of **boilers—single-ended** and **double-ended** (see Fig. 8, Plate 28). The former has furnace doors at one end only. The latter is practically two single-ended boilers placed back to back; it has, therefore, furnaces at both ends, and requires **two stokeholds** (in Figs. 1 and 2, Plate 28, and in Plate 108, the boilers are double-ended). In most cargo vessels the boilers are single-ended; for, with only **one stokehold**, they permit of a short machinery space, and simplify the stoking operations (Plates 109 and 110). The length of the stokehold, from boiler-front to bulkhead, must be such as to permit of the boiler tubes being withdrawn—7 or 8 feet is usually sufficient. Single-ended boilers are always so disposed that the furnace doors and stokehold may be forward. There are several reasons for this. If the stokehold were next the engine room, space would be lost at the backs of the boilers, because, in order that these may be accessible, and to prevent the heat from passing too readily into the cargo hold, a passage about 2 feet wide would be required between; also, an additional bulkhead would be necessary to separate the engine room from the stokehold. When the stokehold is at the forward end it is contiguous to the cross coal bunker, for this, if required, is always placed here; if the cross bunker were between the engine and boilers, it would involve two additional bulkheads instead of one, and a tunnel passageway to the engine room. The backs of the boilers form the forward boundary of the engine room, and, to minimise their heating effect, and at the same time to keep back the coal dust, a portable screen bulkhead of sheet iron (corrugated or plain) or of wood is usually fitted close against them. In very small steamers and yachts the stokehold is placed next the engine, and is not partitioned off, for the stoking operations may then be undertaken by the limited engine-room staff.

In small vessels there is usually one single-ended boiler, but, of course, it may vary greatly in size and steam-raising power (Plate 109). A common size for a large boiler is a length of about 10 to 11 feet, and a

diameter of 14 to 15 feet; but this may be greatly exceeded, a diameter of 18 feet being sometimes attained. When so large, very thick plates are required to withstand high steam pressure—a thickness of over $1\frac{1}{2}$ inches is not uncommon. To withstand the same pressure, the shell of a small boiler might be quite thin; the walls of a steam pipe, for instance, though connected with a boiler having a very thick shell, need only be a small fraction of an inch in thickness. When more steam-raising power is required than a single-ended boiler of moderate size can supply, another is added abreast of it (see Figs. 4 and 5, Plate 27). Or if the vessel is narrow, or if large side coal bunkers are required, one double-ended boiler may be substituted. In larger or higher powered vessels the usual outfit is a pair of double-ended boilers, but in very large ones there may be three (Fig. 3, Plate 27). In high-speed ocean liners there are usually two or more distinct boiler rooms, each containing three, four, or six double-ended boilers, in athwartship rows (Figs. 1 and 2, Plate 28). In some of the largest Atlantic liners there are as many as sixteen boilers, twelve of which are double-ended. A fore-and-aft stokehold and athwartship disposition of the boilers, although at one time not uncommon, is now very rare.

Art. 230. When in port the main boilers are cooled down for overhaul, and as at such periods steam may still be required for various purposes, practically all vessels are provided with a small **donkey boiler.** It may be required for driving the winches and deck machinery, for the ballast and bilge pumps, for lighting and ventilating machinery, and steam-heating pipes. In small vessels the donkey boiler is usually a vertical one (Plate 109); in larger, having more auxiliary machinery, it may be a small single-ended one of marine type (Plates 108 and 110). It may be placed **in the stokehold, or on the upper deck** within the machinery casing. An elevated position is advantageous in that a supply of steam is at all times assured; when in the stokehold, should water by accident gain access to the machinery space, an accumulation only a few feet in depth might, by extinguishing the fires, preclude the use of the steam pumps, so necessary for its removal. A stokehold donkey boiler is often of vertical type, for it occupies little floor area, and may be placed out of the way, close to the vessel's side, or at the centre line in a small recess in the transverse bulkhead (Plate 109). In large vessels having numerous main boilers, one of these, usually one of a pair of single-ended boilers, placed back to back, is requisitioned to do the work of a donkey boiler. When on deck, the donkey boiler is usually of marine type, and is placed within the boiler casing, contiguous to the funnel. The strong beams of I section, introduced at this part, form a suitable supporting platform, for which purpose they are plated over and covered with cement.

A stokehold donkey boiler should be so disposed as to permit of access for cleaning and painting all around and underneath it. When placed close against the ship's side, the frames and shell plating may become seriously corroded, and if there is a plated deck just above the boiler, it also may quickly corrode, and more particularly if coals are carried in the 'tween-deck space above. When placed in a recess in the bulkhead, there should be about 2 feet of clearance all round, and 4 feet above the top of the boiler; very commonly there is only about 9 inches from the boiler to the recess bulkhead, in which case the latter should be properly insulated on the hold side (Plate 109), so that the heat may not pass through and damage cargo, or, if there is a bunker on the other side, cause dangerous heating of the coal (see Art. 454).

Art. 231. The **coal-bunker space** required in any particular vessel depends on her trade, whether her voyages are long or short, and whether

or not the bunkers may be replenished at intermediate ports. It also depends on the efficiency of the machinery; an old vessel, with antiquated engine and boilers, may require, for the same power, 20 or 30 per cent. more coal than a modern one. In new vessels, however, any small difference in the efficiency of the machinery does not materially affect the question of bunker capacity. It also depends on the quality of the coal; a vessel using only inferior coal—such as Japanese, with its 60 or 70 per cent. of ash—would require larger bunkers than one using only Welsh coal. As the time occupied in any particular voyage may vary greatly, a margin of coal—based on the most protracted voyage—must be carried. In large vessels of the liner class, which are always on one route, the coal bunker accommodation may be adjusted to their requirements, with an ample margin for contingencies. In vessels of the tramp class, which have no fixed trade or route, the coal required may vary with each voyage; such vessels must, therefore, have large bunkers, or a space may be arranged as a temporary or permanent reserve bunker, *i.e.* in such a way that it may be used either for coal or cargo.

The **arrangement of the coal bunkers** varies greatly. There are two distinct kinds of bunkers—side bunkers, formed by partitioning off the vacant side spaces in the hold and 'tween decks alongside the engine and boilers (Plate 27); and **cross bunkers,** formed by partitioning off a small portion of the hold right across the ship (see Figs. 1 and 2, Plate 28, and Plate 110). As a permanent cross bunker reduces the length of the cargo holds, it is only adopted when the side bunkers alone are too small. They are required in all ocean-going, high-powered vessels, and particularly in those carrying passengers, where the side 'tween-deck spaces amidships, ordinarily used for coal, are appropriated for passenger accommodation. In slow-going cargo vessels of moderate size the side bunkers alone may be so large as to provide space, on ordinary voyages, for a sufficient supply of coal. The capacity of the lower side bunkers depends, of course, on the vessel's beam and the number and size of the boilers; in some vessels there may be a large space and in others none at all. As usually arranged, there is room for a bunker alongside both the boilers and engine, but, in way of the latter, it may only be on one side, and only for part of the length, so as to give access to the various sea cocks on the vessel's side, and afford space for auxiliary machinery—pumps, dynamos, etc. In many cases, however, although there is room for a bunker alongside of the engine and boilers, it is preferred to leave an open space, so that the capacity of the engine and boiler room may be such as to allow of the maximum tonnage deduction for propelling power. Except in passenger vessels, the 'tween-deck spaces alongside of the machinery casings are always appropriated for coal, and in many cases coal is carried on the upper deck, in the bridge house.

In each side bunker bulkhead there is a small coal door (Fig. 2, Plate 70, and Plate 109) opening into the stokehold. As the lower bunkers are emptied they are replenished from the upper, the coal falling automatically, or being trimmed by hand, through small coaling holes provided in the deck (Fig. 6, Plate 27, Fig. 1, Plate 29, and Fig. 4, Plate 86). In the absence of lower side bunkers, the coal in the 'tween-deck bunkers is conveyed to the stokehold by means of **pocket bunkers.** These may be described as the end portions of a lower side bunker, for although there may be no space for a bunker alongside of the boilers, there is at the side of the stokehold, where quite clear of the boilers. A pocket bunker is thus a conduit for passing coal from the 'tween-deck bunkers to the stokehold. Often, however, they are of fair size, and in cross-channel or river steamers,

making short runs, one at the side of each stokehold may hold all the necessary coal. A communicating passage is required between the engine room and the forward stokehold; with single-ended boilers it is contiguous to the ship's side (Fig. 4, Plate 27); with two double-ended boilers, the two stokeholds may communicate by a passage between the boilers. Although there may be no space for a side bunker directly alongside the boiler, there usually is above, in which case its bottom is formed by a wide side stringer plate, and its side by a sloping casing overhanging the boiler (see Fig. 3, Plate 27). When there is a coal bunker at the side of the engine room, it is usually wider than that alongside the boilers. Its coal is directly available for the after-stokehold by a door in its forward end; if there is only a forward stokehold, the coal must be transported along the passage in wheel-barrows. In large vessels, where the bunkers are extensive, an immense amount of manual labour is expended in trimming and conveying the coal from far-lying points to the stokeholds.

Art. 232. In **warships** the coal is all carried in **side bunkers**, for when so placed it is an important means of defence against gunfire and shell explosion, this characteristic being developed to the fullest extent by extending the bunkers from well above the waterline right down to the bilge, so that the machinery space is surrounded by a **continuous wall of coal** (Plate 113). The retaining bulkhead is watertight, so as to form a complete inner skin, and numerous watertight divisional bulkheads are introduced, so that should a shot penetrate the side and be brought up by the coal, the effect on the vessel's flotation would be small. Below water the bunkers may be comparatively narrow, but above, where more exposed to gunfire, they may occupy the greater part of the 'tween-deck space. In case water should follow a shot through the 'tween-deck bunkers, the machinery casings are also made watertight, and to admit of holes in them and in the side bunker bulkheads being readily plugged up, *cofferdams* are introduced. These may be described as high external coamings, forming with the bulkhead or casing a sort of trough, into which, and over the hole, soft leak-stopping material may be forced.

Art. 233. In merchant vessels, when additional coal space is required, **cross bunkers** are provided; if the boilers are single-ended, one only, at the forward end, next the stokehold; if double-ended, another, usually a smaller one, may be introduced between the engine room and after stokehold, having a tunnel or passageway to the engine room. With a permanent forward cross bunker there are two bulkheads between the boiler room and the hold, and as only one of these need be watertight, the question arises, which should it be? As regards the efficiency of the bulkhead, it is better that it should be the forward one, for if it is the other, the coaling doors into the stokehold must be watertight, and, as noticed in Art. 413, while watertight doors are always undesirable, they are particularly so in a bunker bulkhead. By making the forward bulkhead the watertight one, not only are watertight doors dispensed with, but the other bulkhead may be incomplete so that the side bunkers may communicate with the cross. Nevertheless, unless the cross bunker is small, its after bulkhead is usually made the watertight one, for, being then entirely shut off from the boiler room, it may be used as required for either coal or cargo. When so designed it is termed a "**reserve bunker.**" In tramp cargo vessels the cross bunker is formed in a temporary fashion, by erecting a wooden partition across the fore hold (and, if necessary, in the 'tween decks as well), in such position fore and aft as will cut off sufficient space between it and the stokehold bulkhead for the required coal, the shipment of which is provided for by a special hatchway (Plate 110). A wood bulkhead is,

of course, undesirable for a coal bunker, for should the coal take fire spontaneously, the conflagration might not be confined, but, spreading through the cargo hold, might have disastrous results. When a vessel, having a permanent cross bunker, has to make a long voyage without recoaling, a portion of the fore hold in front of the **permanent cross bunker** is sometimes partitioned off as a **temporary bunker** (see Fig. 2, Plate 28). The coal it contains is used during the outward run, so that on the homeward passage it may be again thrown into the hold and used for cargo; and in order that, on the outward passage, the coal may be conveyed to the stokehold through the full permanent one (reserved for the passage home), a tunnel is built through the latter. This must, of course, be provided with a watertight door, and if placed at the end remote from the watertight bulkhead, the tunnel must be watertight.

Sometimes the **forward cross bunker** is designed for the threefold purpose of a bunker, a **small cargo hold**, and a **water-ballast tank**. When so arranged, watertight hatchways must be provided, and a centre-line, wash bulkhead. And the watertight doors in the stokehold bulkhead must be of a particularly efficient design, for as it may be their duty to withstand a high pressure of water, they must be absolutely watertight—a perfection not usually attained in ordinary watertight doors. This difficulty may be avoided, however, by bolting portable plates to the bulkhead in front of the doors, on the occasions when water ballast is carried. In large cross bunkers a central fore-and-aft bulkhead is sometimes fitted, in order to minimize the chance of the coal shifting, with, perhaps, dangerous consequences to the men engaged in trimming it. Large openings may be provided in its lower part, so that should one side of the bunker be empty before the other, the coal may be trimmed athwartship.

Art. 234. Fast **Atlantic liners** may burn as much as 500 or 600 tons of coal per day; their **bunkers** must, therefore, be large, capable of holding from 4000 to 5000 tons.[1] As all the 'tween-deck spaces are here appropriated for passengers, large lower cross bunkers are essential (Figs. 1 and 2, Plate 28). There is one between each group of boilers; or, if there are no side bunkers, one for each stokehold. Each transverse row of boilers is usually placed in a distinct watertight compartment, so that one bulkhead of each intermediate cross bunker must be watertight, and have watertight coal doors. To avoid these very undesirable doors, the watertight bulkhead is sometimes placed in the middle of the bunker, dividing it in two, so that the one half may serve the stokehold before it and the other the one abaft it. This is also advantageous in that should one of the boiler rooms be accidentally flooded, the adjacent one would still have its full supply of coal. It is usual to provide a tunnel passageway through each bunker, so that there may be free communication between the engine room and the various stokeholds; and, of course, where watertight bulkheads are traversed, watertight doors are fitted (Fig. 2). This is a convenience for the engine-room staff; it is not essential, however, and is undesirable because it greatly increases the possibility of disaster by collision (see Art. 413). The objection may be well met, however, by locking all watertight doors when at sea, or in foggy or thick weather; in harbour they may be opened to secure the convenience of through communication during the usual overhaul and repair work.

Art. 235. To fill the bunkers, small coaling hatchways are provided in the various decks. The coal, falling from above, naturally accumulates

[1] The Hamburg-American liner *Deutschland*, one of the fastest vessels on the Atlantic, burns on an average 572 tons of coal per day when steaming 23·36 knots, and has bunker capacity for 4820 tons of coal.

in a heap under the hatchway, and in order that it may completely fill every part of the bunker, it has to be *trimmed* or levelled up by hand. To minimize this work and expedite the coaling, the hatchways should, evidently, be numerous and well distributed. Their precise arrangement depends much on the coaling facilities of the particular ports at which the vessel fills her bunkers. In ports in which the coal is produced and from which it is exported, whole truck loads may be tipped on board, either by upsetting the truck into an inclined shoot having its mouth over the hatchway, or by lifting it bodily, swinging it over the hatchway, and up-ending it. To coal in this manner, the hatchways should be fairly large. In most cargo vessels there is a *saddle-bottom*, trunk hatchway in the boiler casing (Fig. 1, Plate 29, and Plate 109), through which large quantities of coal may be shot simultaneously into both side bunkers, the remote parts of the bunkers being filled through one or two small hatchways provided in the deck on either side. In order that the coal may fall directly into the lower bunkers, the hatchways in the different decks should, of course, be placed over one another.

The **coaling hatchways** on the upper deck must have a coaming, so that they may be securely battened down, and this, even though there is a bridge or awning deck above, for the latter is not always permanently and substantially closed, and so cannot at all times be depended upon to exclude sea water from the deck below. The coaling hatchways in the lower decks are often termed "*coal holes*" rather than hatchways; they have no coaming, and the deck beams are not cut; it is necessary, however, to fit an angle-bar frame around them, to protect and stiffen the edge of the plating, and so that they may be closed if required by wooden hatches; and the exposed tops of the beams should be doubled, to protect them from excessive wear and tear (Fig. 1, Plate 58). The holes are made long and narrow, so that while providing a large opening, they may reduce but little the cross sectional area of the deck plating. To coal readily and quickly, with a minimum of hand trimming, they should be large or numerous, so that the coal in the upper bunkers may fall automatically, or be readily trimmed, into the lower. Small supplementary holes may be required at different places, to trim the coal through, or serve as exits or "*escapes*" for the men who go into the bunker, while it is being filled, to trim the coal; for, in their absence, when the bunker is nearly full, the men might find difficulty in getting out. For a similar purpose, small holes, about 2 feet square, are often provided in the deck (near the vessel's sides, remote from the hatchways) over holds in which bulk grain may be carried (Fig. 2, Plate 27). Their principal object here, however, is to permit of grain being loaded through them, so that there may be no vacant spaces left in the holds.

In some ports (London, Liverpool, and others) the coal is brought alongside in barges, and is then hoisted or handed up in baskets, and either tipped through numerous small **coaling ports** in the vessel's side, in way of the bunkers (Fig. 3, Plate 60), or conveyed along the deck to the various coaling scuttles or hatchways. In some Eastern ports the coal is carried on board by natives; many hundreds may be engaged, each one carrying a small basket of coal. In some passenger vessels and war-ships which may have to coal in this way, numerous deck **coaling shoots** are provided, so that the bunkers may be filled with little or no trimming. These shoots are plated tubes, about 20 inches diameter, extending from the bunker to the upper deck through the passenger accommodation in the 'tween decks. Where they traverse and would obstruct a passageway, they may be made portable, and are then only shipped during the coaling

operation. At their termination on the upper deck they are provided with flush cast-iron covers (Fig. 5, Plate 28), closed with a bayonet joint, and made watertight with rubber packing. Grating covers are also provided, which, when substituted in fine weather, serve to ventilate the coal bunkers, and, when the top is removed, to light and ventilate the alleyways of the passenger accommodation; if a current of air is desired, cowl ventilators may be fixed in some of the holes. The grating cover lies flush with the deck, but when turned upside down it may be stowed under the solid one. As noticed below, in modern vessels side coaling ports have almost entirely taken the place of these deck scuttles, for, with the former, coaling operations are accomplished without inconvenience to the passengers. Coaling hatchways often require to be *cased* in or *trunked*, so that the coal may pass down to the bunkers without evidence in the upper 'tween-deck passenger or cargo spaces.

Art. 236. In many vessels there is a large **gangway door** in the side of the bridge deck, through which the coal may be carried or run on board in wheelbarrows, to a contiguous coaling hatchway on the upper deck (Figs. 7 and 8, Plate 26, and Figs. 2 and 4, Plate 60). In large modern passenger vessels numerous small **side coaling ports**, about 20 inches square, are cut in the shell plating in way of the 'tween-deck bunkers (Fig. 3, Plate 60). They should not be so low down as to be submerged, for, as they may be opened at frequent intervals, and closed with varying degrees of care, a considerable risk might attach; the security of the ship would be too much dependent on irresponsible individuals.[1] The ports are hinged, and are secured in substantial fashion, usually by tap bolts, inserted and hove up from the outside, watertightness being secured by soft packing. They may be hinged sideways, upwards, or downwards; the last method is advantageous in that, by fixing side flaps to the door, it forms, when open, a natural shoot or scoop, into which the baskets of coal may be emptied (Fig. 3). When coaling through these ports, a stage is hung just below them. As the coal accumulates on the lower deck in front of the coaling ports, it must be trimmed away by hand, and thrown into the lower bunker through a contiguous coal hole. This may be avoided, however, by providing a small coal hole in the deck immediately in front of each port (Fig. 3). Fig. 6 shows an arrangement adopted in large passenger vessels; it will be observed that, to admit of the lower bunker being filled or replenished while the 'tween-deck bunker is still full (or where this space may be devoted to passengers), a trunk or casing is built, in the side of which there is an opening with a flap, which may be hinged into the trunk so as to deflect the coal when required into the 'tween decks.

Art. 236A. The use of petroleum as fuel in steamers, although far from general, is now becoming fairly common in the case of vessels carrying bulk oil, and those trading to ports where the oil is produced, and where it may be procured cheaply. In vessels intended to burn liquid fuel exclusively, there need, of course, be no coal bunkers, their place being taken by oil tanks. To economize space, the double bottom in the machinery space and the peak tanks are commonly used for storing the oil; otherwise, tanks may be built at the sides of the machinery space, the side-bunker bulkheads being strongly constructed and made oil-tight; or self-contained tanks may be fitted in the 'tween decks or bridge. When the double-bottom tanks are used for carrying the oil, they must be specially constructed, so as to ensure absolute oil-tightness. Lloyd's rules in this respect are as follows:—they require the seams of the tank-top plating

[1] The s.s. *Austral* was sunk in harbour through the water entering the open coaling ports as the vessel took a list.

to be double riveted, and the rivets to be spaced $3\frac{1}{2}$ diameters apart, instead of the usual 4 diameters; the spacing of the rivets in the shell landings to be reduced by the addition of two rivets between the frames, and the rivets connecting the frames and reverse frames to the shell and tank-top plating to be spaced 6 diameters apart, in place of the usual 7 diameters. The tanks must be tested with a head of water 12 feet above the load waterline, instead of *at* this level, as with ordinary double-bottom tanks. Ceiling planking over oil tanks must be laid on grounds at least 2 inches thick, to ensure oil leakage—if any—flowing to the side gutters without saturating the planks or affecting the cargo. The supporting bearers, etc., for the stokehold plates must not be of wood, for, when saturated with oil, they would emit dangerous vapour and might take fire. The pipes and valves used for pumping the oil tanks must be distinct from those used for pumping the bilges or pumping and flooding the water-ballast tanks, otherwise oily water might gain access to the latter places, with danger of explosion through the accumulation of oil vapour. All air pipes to the oil tanks must extend to the weather deck, and be permanently open. Oil-fuel tanks in the boiler space must be insulated against the passage of heat from the boilers. The "flash point" of oil used for fuel must not be less than 150 degrees Fahr., oil having a lower flash point being too apt to give off inflammable vapour.

CHAPTER XVIII.

Art. 237. In order that the **engine** may run steadily and smoothly, with a minimum of vibration, it must be firmly bolted to a solid foundation. The foundation of a land engine is a solid block of concrete; when securely bolted through this, the engine and block become one inert mass, perfectly steady as a whole, and incapable of transmitting elsewhere internal vibratory effects. In a ship the **foundation, or seating**, is a tabular structure of plates and bars, in the design of which it should be studied to secure something of the rigid substantiality of a block of concrete. Were it so slender and flexible as to admit of relative movement or straining in its parts, the side swaying of the engine as the vessel rolled, and the vibratory effects of its heavy oscillating parts, would sooner or later result in a break-down. Further, the bolts holding the engine to its seating—the *holding-down bolts*—would not act together, some, more strained than others, might give way, loosen the contiguous riveting of the seating, or cause fracture of the cast-iron bed-plate of the engine immediately clamped by them. Even though the seating be massive and strong, all engines when in rapid movement are liable to vibrate, an effect which becomes transmitted through the structure of the hull. In this respect a ship resembles a flexible wand in which vibrations, though small near their origin, may become excessive elsewhere.[1]

To reduce them, their first cause, the engine, should be so designed as to run with the least vibratory tendency,[2] and the hull immediately contiguous thereto should be so massively constructed as to check their formation at the outset. Not only should the engine seating be massive and strong in itself, but the contiguous hull as well; and in practice this is observed by increasing the strength of the bottom and side framework in the machinery space.

An engine seat may be described, in a general way, as a thick horizontal plate, supported and stiffened by vertical bearer plates, disposed both athwartship and fore-and-aft, the whole forming a rigid tabular structure (see Figs. 6, 7, and 11, Plate 28, and Fig. 8, Plate 109). It is essential that the bearers should be interwoven, for if all were parallel, their freedom to trip would permit of the whole seating straining from side to side, or fore and aft. The causes conducing to this result may be very commanding, for as the ship rolls and pitches, the lofty engine, with its heavy elevated cylinders, swaying in unison, is only held in place by its bolt attachment to the top of the seating; also, a continuous rocking and

[1] The tendency of the engine to set up vibratory movement of the hull depends much on its fore-and-aft position; if moved a comparatively small distance forward or aft, it may be greatly increased or greatly lessened. For some instructive papers on this subject, see those of Mr. Otto Schlick, and others, in the later transactions of the *Institution of Naval Architects*.

[2] The problem of reducing the vibration of an engine appears to be almost solved by the "*Yarrow-Schlick-Tweedy*" system of balancing the moving parts. See *Engineering* for Dec. 17, 1897.

vibrating effect may be induced by the heavy moving parts of the engine. The precise formation of the seat depends on the kind of framework of the hull—whether the vessel has a double bottom or shallow floors—and on the design of the engine (the engine seat is usually designed by the engine builders).

As the engine stands above the shaft, its vertical position in the ship depends on the height of the latter above the keel. If the shaft were parallel to the keel, its height in the engine room, with the usual large propeller, would be such as to place the engine in too elevated a position with regard to the vessel's bottom framework. To correct this, therefore, one or more of three procedures is adopted. The shaft may be inclined downwards from the propeller, the vessel's framing or the engine seating may be elevated towards the shaft, or the cast-iron bed-plate or entablature of the engine may be deepened so as to extend below the shaft. In practice a combination of these methods is adopted. The shaft is inclined, and although the inclination may be small, the total drop in a long shaft is considerable. The engine seating is built upwards, well above the level of the ordinary floors, depth being an important element as regards its own rigidity, its strengthening effect on the vessel's bottom, and in rendering accessible the spaces below. And the cast-iron bed-plate of the engine may be extended considerably below the crank shaft; but it is usually preferred rather to increase the height of the seating, for then the holding-down bolts, being nearer the shaft and having a less lofty engine to hold in place, have a lighter duty. With this in view, the engine seating is usually raised so high that, in order to clear the circular sweep of the cranks, its central part must be suppressed entirely or cut away under the cranks.

Art. 238. In **vessels having shallow floors the engine seat** may be formed merely by increasing their height (locally, or from bilge to bilge), introducing intercostal plates to hold them erect and rigid, and fitting a thick covering or sole plate to take the holding-down bolts and give general rigidity to the whole (Figs. 7 and 11, Plate 28). In other cases it is formed by fitting continuous fore-and-aft bearer plates above the ordinary floors, with cross diaphragm and bracket plates to support and hold them in place (Fig. 6). To give the necessary rigidity, all such additional parts must be from 50 to 100 per cent. thicker than the ordinary floors, the precise amount depending, of course, on the weight and power of the engine. The ordinary floors are also thickened, and the reverse bars doubled. In large vessels and those of high power, the floors are usually increased in height from bilge to bilge (Fig. 7), for then, being both strong and stiff, they have little or no tendency to vibrate or strain upwards or downwards from bilge to bilge. The vertical stresses tending to the latter result may considerably exceed those prevailing in the cargo holds, because, while the weight of the engine is constant, the upward sea pressure may vary greatly, owing to variations in the draught, due to different conditions of loading—one voyage perfectly light and another heavily laden. Should they deflect, the resulting vertical displacement of the engine would at once throw the shaft out of line, bending it locally at the stuffing box in the engine-room bulkhead. It should be observed that the shaft may also depart from the straight through hogging or sagging of the hull, but the amount of deflection suffered by the ship as a whole is very small (it has been ascertained by numerous experiments that the deflection in calm water due to different conditions of loading—laden amidships and empty at the ends, or *vice versâ*—rarely exceeds $\frac{1}{2}$ inch), and it is improbable, therefore, that, being insufficient to cause straining or rupture of the upper works of the deep and rigid hull, it could prejudicially affect the comparatively

slender and flexible shaft. But besides these afloat stresses, there are the more severe ones experienced by ordinary grounding casualties, and in order that when these occur the bottom structure below the engine may not be readily set up and thus damage the engine and involve costly repairs, an ample margin of strength is evidently very desirable at this part. When the floors are increased in height from bilge to bilge, they may be made of a single deep plate, or a top portion may be added to the ordinary shallow floor. Holes are cut in them through which to pass the keelsons (Fig. 7), or the latter may give place to intercostal plates, care being taken to scarph the various parts, so that there may be no serious discontinuities in the longitudinal stiffness and strength. Access should, of course, be provided to every part of the seating, by manholes in the deep floors and intercostal plates.

The lower part of the **engine** itself, the **bed-plate,** is a massive casting having a flange to take the **holding-down bolts** (Figs. 3 and 4, Plate 28). The latter are usually spaced about 20 inches apart; they pass through the thick top plating of the seat, and in order that this may have a maximum of rigidity against their upward pull, the bearer plates below should be placed close to them. The bolts are usually fitted just clear of the bearer angles, to avoid fouling the riveting and to secure a flat surface for the bolt heads. The top plating of the seating varies in thickness from about $\frac{5}{8}$ inch in small vessels to $1\frac{1}{8}$ inch in the largest; the vertical bearer plates are usually some 25 per cent. thinner. The connecting angles are also of large size and thickness; they are usually doubled throughout, but where there is insufficient space to fit and rivet them, a single large one is substituted.

Art. 239. In a vessel having a **cellular double bottom**, the **engine** may sit directly on the tank top (Fig. 1, Plate 31, and Plates 108, 110), or a distinct **seating** may be interposed (Plate 109). In ordinary cargo vessels the latter plan is usually adopted, but in high-class, high-powered vessels the former is preferred, for it is more efficient in many respects. Whichever plan is adopted, the strength of the tank framework is increased; the floors, if elsewhere on alternate frames, are here placed on every one; or if elsewhere on every frame, the necessary increase in strength is secured by fitting additional intercostals (Art. 181). The reverse frames are doubled, and if the tank top is thickened to form the seating, their scantlings are increased. The thickness of the floors is also increased—if the engine sits on the tank top, very considerably, perhaps 25 per cent., but if a distinct seating is interposed, by little or nothing. If the engine sits on the tank top, the short vertical angles connecting the floors and intercostals, also those on the top edges of the latter, are often doubled, and in some cases the frame angles as well, the actual arrangement depending on the power and weight of the engine.

When a distinct seating is interposed, the construction is a simple matter (see Fig. 8, Plate 109). It usually takes the form of two massive box girders, one on either side of the centre line, each composed of two fore-and-aft bearer plates, connected by a thick covering plate, and having internal cross diaphragms and external bracket plates to hold them erect and stiffen and support the thick top plating. The tank-top plating is here only thickened by about $\frac{2}{20}$ inch.

When the engine sits upon the tank top, the latter is, of course, made specially thick to take the bolting, from $\frac{3}{4}$ inch in small cargo boats to $1\frac{1}{8}$ inch in the largest high-powered steamers. The thick plating is only fitted locally, under the engine, but may extend aft to take the thrust-block. In a twin-screw steamer it may cover the entire tank top,

and even extend beyond the margin plate. It may be worked edge-to-edge, in-and-out, or it may be joggled. When edge-to-edge, the butt straps and edge strips may be placed either above or below; when above, the constructive work is easier and the caulking more reliable, but care must be taken that the holding-down bolts do not foul the caulked edges of the straps; when below, the strips may be fitted either in short lengths between the reverse bars or continuously, but the latter method, unless the reverse bars are joggled under the strips, involves thick liners and much heavy three-ply riveting. When worked in-and-out, the reverse bars should be joggled to avoid thick liners and three-ply riveting. The end joints of the thick plating are double riveted, and the edges, except those of the centre strake, single; but in large vessels all joints are double riveted. As the engine bed-plate does not sit in actual contact with the tank-top plating (or sole plate of an ordinary seating), a perfectly flush surface is unnecessary. When bolting the engine in place, it must be so adjusted that the crank shaft within it may be in line with the distant stern tube, already permanently fixed. To provide, therefore, for vertical adjustment, the bed plate is so designed that, when in its proper place, it may be from 2 to 3 inches clear of the tank top, teak-wood wedges (with or without supplementary iron blocks) being driven tightly in the vacant space, between the holding-down bolts (see Figs. 2 and 3, Plate 28). The latter vary in size from $1\frac{1}{4}$ to $2\frac{1}{2}$ inches, but, of course, much depends on their number. In order that the pull of individual bolts may not cause excessive local stress on the contiguous riveting of the tank-top plating, it is evident that the latter should be thick, that the bolts should be closely spaced; and that the fillings inserted between the tank top and the bed-plate should be close to the bolts; also, that the bolts should be hove up and maintained at a uniform tightness, for it is not uncommon, through some of them working slack (it may be through long-continued racing of the engine), for the riveting of the tank-top plating, contiguous to the tight ones, to loosen under the undue stress.

With a double bottom of the usual depth, the line of shafting, unless it drooped very considerably (a circumstance which would prejudice the efficiency of the propeller), would, in a large vessel, be so high above it as to involve a very deep cast-iron bed-plate (Plate 110). To avoid this, therefore, it is common to **increase the height of the tank in the engine room**, and at the same time incline the tank top fore and aft, so that, being parallel and close to the shaft, it may permit of a shallow, square, engine bed-plate (Fig. 1, Plate 28, and Plate 108). This is also advantageous in that the greater depth of the tank floors gives superior strength to the vessel's bottom, a more rigid foundation for the engine, and a more capacious ballast tank. The greater height need only be local, sufficient merely to take the bed-plate and thrust block; the tank top may slope downwards at either side, but it is usually carried level from bilge to bilge. In large vessels the depth of the engine-room tank when raised in this way may be very great; in some modern Atlantic liners it exceeds 9 feet; and in such cases the deep floors must be additionally supported between the longitudinals, by stiffening bars or by fore-and-aft keelson-like tie bars, piercing them at mid-depth. There should be numerous intercostal plates, but as their chief purpose is to stiffen the top plating against the pull of the holding-down bolts, they need not all—in those deep tanks—extend to the shell. It should be noticed that the flange system of connection is not applicable for the bottom framework in the machinery space, for it is insufficiently rigid, and a double connection is generally required.

With a built-up seating the **holding-down bolts** are ordinary square

or hexagonal-headed bolts (Fig. 3, Plate 28). They are inserted from below, and where a bolt head may foul a bearer plate, part of it may be cut off. When they pass through tank-top plating they are formed as studs, so as to secure perfect and permanent watertightness (Fig. 4). They are screwed through the tank-top plating, and, to prevent them from backing out, and to relieve the thread, a lock nut is screwed on the point below, a soft gromet being interposed as a further precaution against leakage. Where nuts cannot be placed below, the studs may be slightly tapered, so as to jam tightly in the holes, a flat lock nut and gromet being placed above, between the engine bed-plate and the tank top. All such bolt holes are drilled and tapped before the engine is put on board, their position being accurately transferred by template from the bed-plate. The holes should be arranged to clear the joints of the tank-top plating and the reverse frame and intercostal angles below, otherwise they would prejudice the caulking, cut up the riveting, and the lock nuts might not get a fair bed. In special cases, to secure a more rigid holding effect, or where the bolts would necessarily foul the reverse bars, these are made extra wide, and their rivets specially arranged to clear the bolts.

Art. 240. With a continuous double bottom of **McIntyre type**, a distinct **engine seat** is introduced. Here the bearers are placed athwartships, so as to traverse several of the tank girders. The latter, having but a meagre attachment to the floors, and being free to trip, are alone incapable of rigidly supporting the engine seat, and so numerous diaphragm plates are fitted between them, which, forming extensions of the floors, secure their thorough incorporation with the seating above. It is seldom, however, that a McIntyre tank is carried through the machinery space.

Art. 241. The **thrust of the propeller**, in forcing the ship ahead or astern, tends to push the shaft on-end. Now, the crank-shaft of the engine, revolving in simple bearings, must feel none of this thrust, and so, to take it up and convey it to the hull, a cast-iron **thrust-block** is introduced, just abaft the engine (Plates 108 to 110). In order that the shaft may transmit its thrust to the block, a number of projecting collars are forged upon it (see Fig. 7, Plate 30); these fit between corresponding collars (termed "*horse-shoe collars*") in the thrust-block, which, in order that those on the shaft may take the same pressure, are each one made as a separate part so as to admit of individual fore-and-aft adjustment. In order that the thrust-block may perfectly resist the push of the shaft and convey it to the hull without causing local straining, it must, evidently, have a substantial seating and be well bolted thereto (Fig. 9, Plate 109). The thrust is not always a steady force, for in heavy weather, when the propeller is alternately lifted out of the water and deeply submerged, it may one moment be zero, and the next very great. The excessive thrust is due to the engine having raced or acquired a high velocity when the propeller was out of the water, so that, when again suddenly submerged, the rapidly revolving propeller does, for the moment, abnormally great propelling work.

When the **thrust-block** sits on a **foundation**, well below the level of the shaft, the thrusting effect, acting at its upper part, tends to topple it forward, and, by creating a lifting stress on the aftermost bolts, strain them and the contiguous riveting of the seating. As regards the thrust-block and its bolting, this tendency becomes less and less the nearer the foundation is raised to the axis of the shaft, if level therewith it would disappear; the bolts would then suffer only a fore-and-aft shearing stress, of which they are relieved by projecting locking pieces, fitted on the top of the seating in contact with each end of the block. With a view, therefore, to securing

as far as practicable, this desirable condition, it is usual, even though the engine itself may sit directly on the tank top to provide an elevated seating for the thrust-block (Fig. 3, Plate 31, and Plate 108).

Formerly the **thrust-block** was often placed in the tunnel, just abaft the engine-room bulkhead; now it is practically always placed in the engine room, space for it being provided by forming a **recess** in the after bulkhead (see Fig. 1, Plate 28, and Plates 108 to 110). This is advantageous because the block is then more accessible and better under observation—an important matter in a part requiring so much attention. The tunnel abuts upon the after end of the recess, and it might be entered from here, but as it must have a watertight door with closing gear extending upwards to the deck, it is generally preferred to carry it around the recess, by an independent passage (Fig. 6, Plate 109), for as the doorway is then in the engine-room bulkhead, an ordinary vertical watertight door, having direct screw gear, may be fitted, and the recess is relieved of traffic. In large high-powered vessels the thrust-block is placed directly abaft the engine, its forward end abutting on the bed plate (Plate 108), so that its forward thrust may be distributed amongst the numerous holding-down bolts of this part.

The thrust-block seating, when on the top of a double bottom, is formed of a thick horizontal plate, supported by two or three fore-and-aft bearer plates, the latter being held erect by a cross plate at either end, and sometimes by intermediate diaphragm plates (see Fig. 9, Plate 109). In most cases the sides of the tunnel or recess are thickened and made to serve as bearers. The different parts are all very substantial, much the same as those of the engine seating. It is important that the seating should be long, fore-and-aft, so that the thrust may be distributed over a large portion of the vessel's framework, and to avoid the toppling or tripping tendency already noticed. Straining of the thrust seating sometimes occurs; it happens usually as a result of a stormy voyage and long-continued racing of the engine; but, of course, it must primarily be due to lack of strength in the seating itself. In small vessels the length of the seating is about three frame spaces, in large, five or six. Although side bearers only may be fitted, the introduction of a central one greatly increases the efficiency of the seating, for, as it connects to the vertical keel, it is particularly capable in transmitting the thrust; in view of this, it is usually made more substantial than the others. If the tank top is of ordinary thin plating, it is well to introduce intercostal plates under the side bearers, so as thoroughly to bind them to the floors; this is particularly necessary where there is no central bearer, or where the floors may not be on every frame.

In a vessel not having a double bottom, the thrust seating is a more elaborate structure, for it must extend downwards to the shallow floors. It is formed by three fore-and-aft bearers, the side ones connecting to the floors, and the central one to the keelson. If the former sat merely on the tops of the floors, they would have but a poor connection, and so, to improve it and check tripping tendencies in the floors, intercostal plates are introduced. The forward ends of the bearers abut upon the engine-room bulkhead, their after ends being sloped downwards, so as to secure an extensive connection and holding-down effect at this part. To give transverse rigidity, cross diaphragm plates are introduced. The central bearer is here much more capable than the others, for it is shallower, and connects to the massive centre keelson. The bottom of the tunnel intervenes between the thrust-block and the seating. While maintaining the watertightness of the tunnel there are two methods of construction available: either the seating may be built as a support for the tunnel, and another seating—a continuation—erected within, or the bottom of the tunnel may be stepped upwards

to form the top of the seating. Lightening holes are punched in the bearer plates, to give access for the riveting and bolting.

Art. 242. The shaft is supported by bearings, termed "**plummer blocks**," at intervals of 12 to 20 feet, according as its diameter is small or great (Plates 108 to 110). The blocks are bolted to seatings termed the "**shaft**" or "**tunnel stools**" (Fig. 7, Plate 109). They not only support the weight of the shaft, but hold it against any tendency to bend sideways under the longitudinal thrust; as this, however, is a force of no great magnitude, the seatings need not be so massive or extensive as that just described for the thrust-block. In small vessels, two cross bearers and a top plate may suffice, all being connected to one side of the tunnel; in larger, an inner fore-and-aft bearer is added, the stool then forming a box, access to which is provided by lightening holes (Fig. 12, Plate 29). Holes are usually punched in the athwartship bearers, through which bilge and ballast suction pipes may be led. In vessels not having a double bottom, the bottom of the tunnel is raised some feet above the floors and keelson by athwartship bearer plates, arranged in pairs under each stool, so that the latter may have a direct support from the vessel's floors (Figs. 3 and 4, Plate 29).

The foregoing description of the thrust and plummer-block seatings refers more particularly to single screw vessels. In twin screws the same considerations apply, but in the case of some of the after bearings, which sit upon the shelving side or bossed portion of the hull (Fig. 3, Plate 31), special strength and stiffness must be secured by web frames and deep floors, with which the foundation plates of the seating are incorporated (Fig. 5, Plate 30). The furthest aft block, which is quite within the bossing, may be bolted direct to the vessel's frames, these being doubled in way of it.

Art. 243. The shaft must have a bearing close to the propeller, where it passes through the sternpost. This is a very important bearing, for not only must it sustain the weight of the propeller (which may be anything up to about 9 tons, this being the weight of a propeller 17 feet 6 inches in diameter, having detachable steel blades), but hold it against side shocks due to sudden immersion when revolving at immense velocity, blows from the waves (sufficient sometimes to break the blades), and the centrifugal force that may be brought about by the loss of one or more blades. It must, moreover, be a bearing of peculiar efficiency, for at sea it is inaccessible for examination, lubrication, and adjustment. These conditions are satisfied by fixing in the hull a cast-iron tube, termed the "**shaft or stern tube**," which forms a sort of sleeve for the shaft (see Figs. 8, 11, 12, Plate 29). Its outer end is turned to fit accurately in the hole bored in the bossed portion of the sternpost; it projects a few inches beyond, and a large flat nut is hove up on the outside, a screw thread being worked on the tube for the purpose. The inner end is connected by a flange to the peak bulkhead, which is locally doubled or increased in thickness.

In the tube shown in Fig. 11, Plate 29, the shaft does not bear throughout the length of the tube, but only at its ends, at which there is fixed within the tube a bush or journal of brass. The after bush is much longer than the other, and is provided with fore-and-aft slots, in which are fixed strips of lignum vitæ (Fig. 9); the latter project beyond the brass, and alone take contact with the shaft, upon which there is shrunk a brass liner. In ordinary cargo vessels slots are not provided for the lignum vitæ strips (there are only two, for locking purposes), for, like the stones of an arch, they hold themselves in place (Fig. 10). The lower strips, which take the weight of the shaft, are so cut that the grain lies radially. As the shaft does not fit tightly, and as there are channels between the strips, the sea

water is free to enter the tube, and is only arrested by a stuffing box fitted at its forward end, accessible from the tunnel. The water keeps the shaft cool against the heating tendency of friction, and, for the lignum vitæ—a wood of a hard and oily nature—is the best lubricant. So long as sand does not gain access to the tube, the strips may endure for years; in case of stranding, however, the mud and sand stirred up by the propeller may cause rapid attrition of the wood; in which event, as the shaft would begin to bear upon the brass, it may be necessary to dock the vessel, withdraw the tail shaft, and fit new strips. Sometimes, instead of lignum vitæ, white metal or cast-iron bushing is used; for coasting vessels, navigating muddy waters, this is found to have greater endurance, and this with no lubricant but the water. In some cases, however, the tube is filled with grease or tallow, which may be forced in as required from the tunnel. The ordinary bearings in the tunnel are lubricated with grease, but as they constantly tend to heat, provision is made for playing water upon them, by leading a pipe along the tunnel (either from the stern tube or from a sea cock in the engine room), having a cock over each one.

It is important that the **shaft tube** should be fixed with absolute rigidity in the hull, for, should it loosen under the **vibrating and jarring effect of the propeller**, the result might be serious. Much depends on the accuracy of its fit in the sternpost, and then again upon the rigidity of the post itself, and of the adjoining hull with which it is incorporated. In practice the required conditions are secured by giving massiveness to the post, by increasing the thickness of the contiguous shell plating holding it, and by uniting the sides of the hull above and below the tube by deep floor plates. In twin-screw vessels, where the tube may be long, its inertia as a bearing is improved by supporting it at one or more intermediate points by the floors it traverses (Fig. 7, Plate 30), these may be doubled and accurately bored to receive it, or with some clearance, in which case contact is secured by driving iron wedges alongside the tube. In modern cargo vessels the **length of the tube** is usually reduced to some 6 or 7 feet (or about 50 per cent. of what was formerly common), in order that the shaft within it may be so short as to permit of its being entirely covered with a single brass liner (Fig. 8, Plate 29), and thus avoid the corrosive effects noticed in Art. 458; and for this purpose the after-peak bulkhead is either placed close to the stern-frame or a recess is formed in its lower part (see Fig. 12, Plate 29, and Plate 110). At one time it was common, in large vessels having a heavy cast-iron propeller, to provide a bearing for the shaft abaft the propeller, in the rudder post; this is not done in modern vessels, and in the existing ones so designed the after bearing has been discarded. The shafts of a twin-screw vessel are also provided with tubes, to satisfy the essential requirement of an outer bearing, water lubricated, and an accessible stuffing box (Figs. 7 and 8, Plate 30, and Fig. 3, Plate 31). In these vessels the length, position, and mode of fixture of the tubes depends on the particular arrangement of the shafting and its fixture in the hull (Art. 100).

Art. 244. The **shaft tunnel** serves a twofold purpose; it provides at all times, irrespective of the cargo in the holds, a passage alongside the shaft for the engineers, so that they may examine, adjust, and lubricate the bearings and tube stuffing box; and, in the event of fracture of the tail shaft, involving the demolition of the tube and its stuffing box, it confines within itself the entering water. For the latter purpose it must be watertight, and so strongly constructed as to be capable of withstanding the water pressure; for the former it need not be watertight, and in some cases it is not; or when cargo is not carried in the after hold there may be no tunnel at all, but in this case the contingency of a fractured tube

and damaged peak bulkhead is met by a duplication of the latter part (see Art. 207). The tunnel is entered by a watertight door in the engine-room bulkhead (Plate 109). Such a direct entrance is a great convenience, and is only dispensed with in rare cases, in favour of a vertical shaft or trunkway from the deck, which, of course, must be watertight, if the tunnel be so. The tunnel should be of such a size as will provide head room, and a convenient passage alongside the shaft; in small vessels these requirements are often disregarded. It is placed slightly off the centre, to port or starboard, so that the shaft, lying close to one of its walls, may leave a passage on the other side. In vessels having a double bottom, the tank top usually forms the bottom of the tunnel; in a large vessel, therefore, whose shaft lies far above this, a platform of planks, gratings, or plates must be fitted at a suitable height within. In any case, as the tunnel is often awash with the water used in cooling the bearings, a raised flooring is required. Sometimes the bottom is covered with cement, but there is no good in this, for with so much oil and grease floating about there is no corrosion. In vessels having ordinary floors (and sometimes in those having a double bottom) the tunnel is built with an independent bottom, supported from below (Figs. 3 and 4, Plate 29).. When arranged in this way, it need not be higher that 6 or 7 feet, which economizes hold space. The top of the tunnel is rounded, arch-like or only at the corners. In large vessels the third or fourth deck, if plated, is sometimes made to serve as the top of the tunnel.

The tunnel does not usually extend right aft to the after-peak bulkhead, but stops against a dwarf bulkhead forming the forward wall of a small chamber termed the "**stuffing-box recess**" (see Fig. 12, Plate 29). This recess is practically an enlargement of the tunnel; its roof is usually curved to meet the vessel's sides squarely, and thus facilitate the watertight connection. The recess has no bottom, but is open right down to the vessel's keel, so as to form a deep well in which drainage water may collect and be readily removed by the steam pumps, a suction pipe being led thereto for the purpose. In fine-lined vessels, in the absence of a recess, the tunnel sides would meet those of the vessel at an acute angle, incompatible with a watertight connection. The recess is useful in affording space for the extensive operations which occasionally take place here in connection with the removal of the propeller; for to do this the tail shaft must be pulled inwards, which involves the removal of the length of shafting immediately in front of it. And the tail shaft must be withdrawn periodically for examination; because, being always within the tube, its condition as regards flaws and defects—whose development is often curiously rapid—cannot otherwise be ascertained (Art. 458).

In **twin-screw steamers** there are **two tunnels.** Their inner walls usually terminate at a uniting transverse bulkhead, their individuality abaft this being maintained, if required, by a central bulkhead, which, for the convenience of communication, is sometimes provided with a watertight door. Their outermost sides terminate in the manner just described for the tunnel of a single screw, by a square across abutment with the vessel's sides. Just before this point there is a space in the hold, between the vessel's sides and the tunnel, so narrow and restricted as to be of little use for cargo; it is therefore common, in large vessels, to make use of these two spaces for fresh-water or trimming tanks, the top being formed by an outward extension of the tunnel top, and the sides, by the side of the ship and that of the tunnel. In small twin-screw vessels separate tunnels are sometimes dispensed with, the lower part of the hold forming one large shaft chamber.

It is not improbable that the **tunnel may,** as a result of an accident, suffer sea pressure from within or without, tending to **burst or collapse** it. The former event may be brought about by rupture of the tail shaft and tube, and the latter by flooding of the hold through collision. The latter, of course, is the more serious, for the water pressure would be greater due to the large increase in the vessel's draught; and not only is a tube-like structure such as the tunnel less capable of withstanding external pressure, but there is a chance of its being injured by blows from floating cargo. In vessels whose bulkhead subdivision is so perfectly arranged that the flooding of one of the after holds would not in itself be fatal, an imperfectly constructed or defective tunnel might have disastrous consequences, rendering useless the subdivision by bulkheads; for if it collapsed in way of a flooded hold, or leaked so badly as to fill, it might fail again, by internal pressure, in way of an adjacent hold, otherwise kept free from water by the bulkheads. It is not improbable that defective tunnels have contributed to the loss of many vessels. Their integrity as a watertight tube is often sadly neglected. It is common to find unfilled bolt holes, and in old vessels cracked plates and open joints; suction pipes may pass through its sides or bottom without proper jointing, and the large ventilator pipe leading from its roof, instead of being watertight and of substantial thickness, may be of thin uncaulked sheet iron, perhaps corroded through in holes or broken by blows from cargo. Again, its watertight door in the engine room may be jammed (this is often done by the engine-room staff, to prevent it from jarring at sea) permanently open, and the shaft stuffing-box in the engine-room bulkhead may not be watertight. That such conditions should prevail is due to those in charge being ignorant of the important duty which the tunnel may be called upon to fulfil, or to their assuming that the contingency of a flooded tunnel or hold is too remote to warrant serious consideration.

As regards the **construction of the tunnel,** Lloyd's rules require its plating to be the same thickness as the lower part of the transverse bulkheads, stiffened by angle bars the size of the reverse frames, placed 4 feet apart; but when the sides or roof present a large flat area, or where the tunnel passes through a deep tank, the stiffeners must be placed about 2 feet apart, to give the necessary strength against water pressure. Either steel or iron may be employed, but the latter is much the less suitable, and is now rarely used; it is common to find the plates of an iron tunnel cracked and broken by blows from cargo. The plating is usually disposed in fore-and-aft strakes. The stiffeners are worked in continuous arches; they are usually placed inside, for when outside they are exposed to the battering effect of cargo. The top under the hatchways is specially exposed to blows from cargo during loading and discharging operations; its strength is, therefore, increased at these places by fitting the stiffeners 3 feet apart instead of 4, and by thickening the plating or sheathing it with wood. If sheathed, the planks are usually bolted in place, but unless tap* bolts are used, having nuts within the tunnel, it is better to clamp them in place by external iron bands, for should the bolts break and not be replaced (a common occurrence), the watertightness of the tunnel would be destroyed. More usually, wood sheathing is dispensed with, as it requires frequent renewal, and the top plating under the hatchways increased in thickness by 25 or 50 per cent. In coasting vessels which carry coal, pig iron, ore, etc., a V-shaped saddle-plate is sometimes placed over the tunnel, to shield it from the battering effect of the cargo thrown violently from above.

It sometimes happens that the tail shaft has to be renewed, on which

occasions some of the tunnel plates and stiffening bars may require to be cut adrift to pass in the new one and remove the old. It is well, therefore, to provide for this, by suitably disposing certain plates, and jointing the contiguous stiffening bars. In modern vessels a **spare tail shaft** is often stowed within the tunnel, in a long recess or chamber at its after end (Figs. 5, 6, 7, and 12, Plate 29); this is an excellent plan, for the substitution of the new for the old may be made without delay, and the old shaft may be readily withdrawn endwise from the tunnel, by removing a small plate on the end of the recess.

Art. 245. The **engine of a paddle steamer,** and its mode of **fixture in the hull,** differ entirely from those of a screw engine. The latter has only one foundation or point of attachment, over the keel; and this is well placed as regards both the hull and the engine, for the structure of the former has here a maximum of rigidity, and it is close to the crank shaft, where the straining and vibrating effects are greatest. Further, the shaft, leading away from the engine, although remote and independent, forms with it practically one rigid whole, for both are supported from the rigid keel line. A paddle engine may be regarded as including the heavy overhanging wheels, and while, therefore, it is very incompact, it cannot, as in a screw engine, be supported from one foundation: the cylinders are fixed to the bottom of the hull, the crank shaft is supported by bearings at the deck level, and the wheels by a bearing at each gunwale (see Fig. 5, Plate 31). In order that, when thus supported, at widely distant points, it may form one rigid whole, it is evident that the hull, at and between these points, must have so much continuous rigidity in itself as practically to form one foundation. As the hull of a paddle steamer is usually of very light scantlings, special local reinforcements are required to secure this result.

The cylinders of a paddle engine are bolted to the vessel's bottom, as low down as practicable; when of the usual diagonal type, they lie abaft the crank shaft, inclining upwards towards it (see Fig. 5, Plate 31). The bearings of the latter, situated just above the deck level, are held by the rigid framework of the engine; they are, therefore, in one piece with the cylinders, and derive their support from the same foundation—the bottom of the hull. To support the heavy overhanging wheels, to take their forward thrust and hold them against shocks from the waves, the shaft must have very powerful bearings, one at each gunwale; and, to reduce to a minimum the stresses on the shaft, they should be placed as close as possible to the centre line of the floats. They are, therefore, fixed on *sponsons* or brackets, built on the outside of the hull (see Fig. 5, Plate 31, and Figs. 2, 4, 5 and 6, Plate 32). There are thus three distinct points of support; the two bearings at the gunwale, supporting the heavy live load of the wheels; and the vessel's bottom, supporting the remainder. These points are widely distant (in a large vessel the wheel bearings may be 40 feet apart), and yet it is essential that they should be so united that, whatever the straining forces affecting each one, there may be no relative movement. In a lightly constructed paddle vessel this might readily occur, and as it would involve bending of the shaft and friction in the bearings, the result might be serious. The necessary continuous transverse rigidity may be well secured by fitting, close to the shaft, a transverse bulkhead, to which the frame of the engine contiguous to the crank shaft bearings may be connected, as also the aforesaid sponsons on the vessel's sides (Fig. 5, Plate 31). When supported in this way, by a single rigid bulkhead or diaphragm, the shaft is unaffected by straining tendencies in the hull. If, as is usual, a bulkhead cannot be fitted, then its marginal part—or an

equivalent—may be substituted, in the form of a powerful cross beam, formed of plates and bars in a semi-box formation, and by one or more closely spaced web frames, extending around the hull from gunwale to gunwale (Figs. 2 and 6, Plate 32).

The **bottom seating** need not be so rigidly constructed as that for a screw engine, for, relatively to the weight supported, it has a larger base of attachment, it has supporting and steadying points on deck, and it runs slowly, with little vibration. It is usually constructed by fitting in the engine room two additional intercostal side keelsons, and by increasing the massiveness of the centre keelson; these form fore-and-aft bearers for the engine bed plate, their upper flanges are made wide and massive to take the bolting, and, to give the necessary transverse strength, some of the floor plates may be increased in depth, and continued up the sides as web frames.

The **sponsons** supporting the paddle-wheel bearings are usually formed like the segment of a cylinder (Figs. 4, 5, and 6, Plate 32). They have a similar duty to the thrust seating of a screw vessel, but in heavy weather they are exposed to violent shocks as the wheels become choked in passing waves. They must, therefore, be very substantial. In a large vessel the top plate taking the bolting is about 1 inch thick, and the others $\frac{3}{4}$ inch; and within it there are several reinforcing brackets, all connected by heavy angles (Fig. 4). Its connection to the vessel's side is usually made by flanging the edge of its outer plating, for an angle bar would require an excessive bevel. If riveted to the ordinary thin shell plating, its special strength would be of little value; this, therefore, must be doubled or increased in thickness, and the framework within reinforced as already described, by one or two web frames and additional side stringers.

Art. 246. The **Paddle wing,** built around the wheel, is an important part of a paddle steamer (Fig. 6, Plate 32). It supports the paddle box and protects the wheel when the vessel goes alongside landing stages, etc.; and its outer part, in way of the wheel, forms a support for the eccentric bearing which controls the feathering mechanism of the paddle floats (Fig. 2). It must be powerfully constructed, for it may receive crushing blows from quay walls and violent upward shocks from the waves. The construction may be described generally as follows: Contiguous to the wheel, before and abaft it, a powerful bracket-like beam, termed the "*paddle beam*," is fixed, projecting from the vessel's side at about the level of the deck (Figs. 2 and 6). The outer ends of these two beams are united by a vertical tie plate, having stiffening angles on its upper and lower edge, and covered on the outside by a stout balk of oak or elm; the whole thus forms a composite beam or girder, stout and strong in the resistance it offers to impact with quay walls, etc. To its inner surface is bolted the eccentric bearing just mentioned, and upon the square frame thus formed around the wheel the paddle box is built. The fore-and-after of timber and plate is continued—the timber only in small vessels—beyond each paddle beam, sloping gradually into the vessel's side; and to hold it at fixed distance therefrom, light subsidiary bracket beams are introduced. A platform termed the "*wing*" is thus formed before and abaft the paddle box. In American river steamers it is carried from stem to stern, affording large deck area and accommodation for side cabins; in paddle steamers in this country it is only sufficiently long to cover the wash of the paddle wheels and offer a sloping fender, such that the vessel may be readily moved along in contact with landing stages, etc.

As the paddle wing forms a large flat surface (in channel steamers it may be 15 feet wide) it is particularly exposed to violent upward shocks

from the waves. Its connection to the vessel's side must, therefore, be very substantial. The **paddle beams** must be particularly strong, for they have to support the paddle box and the long fore-and-aft girder on their outer ends against the crushing pressures incurred when going alongside landing stages, etc. Formerly they were fitted right across the ship, in one piece, but now they are built as independent brackets, securely incorporated with the hull by fitting opposite each one a deep web frame (Figs. 1, 2, and 6, Plate 32). In large steamers the latter extend up to the promenade deck, and are united at each deck by substantial cross beams; in this way the sides of the hull are well reinforced against shocks acting on the outside of the paddle wings. The paddle beams themselves are usually formed of a single plate, lightened with holes, and having around its edges, a double-angle frame. In some cases, instead of a plate lightened with holes, a lattice formation is adopted, but this is much less capable of resisting end-on shocks. In large vessels, the better to support the ends of the paddle beams, a plate stay is fitted, extending diagonally from their outer ends to the top of the web frame at the promenade deck (Fig. 2). In channel steamers the small subsidiary bracket beams supporting the wing are formed in a similar way, but less massively. In river steamers they are of angle or tee bar, kneed downwards at their ends and supported from the vessel's side by round-iron stays (Fig. 3). The latter should connect to the vessel's side with a large palm, and the thin shell plating should be locally doubled, for if not they might, in case of accident, tear open the sides, with perhaps serious consequences.

In river steamers the paddle wing is merely planked, in channel steamers it is plated; and, in the latter, to break the shock of waves when they strike the platform from below, fore-and-aft bars of half-round iron are riveted, a few inches apart, to the sloping edges of the supporting beams (Fig. 1, Plate 32). The timber belting, forming the outer margin of the sponson, is of elm, steamed and bent to shape. It is usually worked in two thicknesses, with well-shifted scarph joints, and upon its outer surface there is fitted a rubbing plate, which should be thick and, if practicable, jointless.

The **paddle box** has no structural duties (Figs. 1 and 2, Plate 32); it forms a mere covering for the wheel, to shut in spray; it may, therefore, be of slender construction, but as it offers a large surface to flying masses of water, it should be sufficiently substantial to resist their concussive effects. It is formed of sheet steel, $\frac{1}{8}$ or $\frac{3}{16}$ inch thick, but in small vessels it is sometimes made of feather-and-grove planking, about $1\frac{1}{2}$ inch thick. It is stiffened and supported by light angle bars, bent to the fore-and-aft contour of the box. The inner vertical wall is of thin plating, but the outer is usually of wood, this material lending itself to the ornamental open fretwork conspicuous in nearly all paddle steamers. In channel steamers the side plating of the hull is usually extended up to the promenade deck (except at the after end, where there is less chance of sea and spray leaping on board), and in way of the paddle wings the topside plating is carried outwards around them, the enclosed spaces forming convenient locations for water-closets, galleys, etc. In small river steamers the paddle wings are often left open, to form gangways and mooring platforms; but, adjoining the paddle box, small houses are built for galleys and water-closets, this situation being particularly suitable for the latter, because it is in the open, remote from the living spaces, and the spray from the paddle wheels affords a constant supply of water for flushing purposes.

Art. 247. In high-speed **cross-channel and river steamers** the

boilers are sometimes of so large a diameter as to necessitate the suppression of a large portion of the upper, or main, deck, leaving a mere margin on either side (Fig. 5, Plate 31). This, of course, is in consequence of the shallowness of the hull, for in these vessels the upper deck, in its relation to the boilers, occupies a similar position to the lowest deck of an ordinary cargo vessel, which, as noticed in Art. 156, may have to be entirely suppressed in way of the boilers. On account of their small depth and relatively great length, these vessels are liable to intense **longitudinal stresses**, more particularly channel steamers, which encounter large waves, and as the heavy machinery, concentrated amidships, is practically the only weight carried, sagging stresses are more severe than hogging (Art. 8). Special care must, therefore, be taken to ensure sufficient longitudinal strength in the upper deck where cut away by the machinery openings. This may be done by fitting thicker plating on the existing marginal parts, and by so designing the fore-and-aft coaming plates of the openings that, besides supporting and stiffening the deck, they may contribute useful longitudinal strength; also, by fitting below the marginal parts of the deck one or two fore-and-aft keelson-like stringers, connecting them to the plating between the beams, so as to give it the necessary stiffness under longitudinal compressive stress. If the promenade deck is carefully designed with continuous fore-and-aft material, and rigidly united to the main structure of the hull, it may form so substantial a portion thereof as, in effect, to increase the vessel's depth and greatly improve her strength as a long girder. The sides of the hull in the machinery space, where many beams are severed and where the greatest load is carried, must be well stiffened by web-frames, so that, under longitudinal bending forces, they may be held to their work, free from any transverse straining tendency. The influence of web frames in this respect may be readily appreciated by the simple experiment of bending a shallow trough, say of paper; under the external bending force the sides will be observed to fold over transversely.

Art. 248. Boilers do not require such extensive seating as an engine, for although they may be very heavy, they are an inert dead-weight. They sit in cradles, termed "**boiler bearers**" or "**stools**," formed by a vertical plate, the upper edge of which is curved to the radius of the boiler shell (see Fig. 5, Plate 27; Figs. 8 and 9, Plate 28, and Plate 109). For a short boiler, two stools in the length are sufficient; for a large double-ended one, three, or even four may be necessary (see Plate 108). They must be massively constructed, for they require a large margin of strength. When full of water a boiler is a very heavy mass; a single-ended boiler, about 16 feet in diameter, may weigh 70 tons, but a large double-ended one may weigh as much as 150 tons. Their weight, moreover, may, in effect, be greatly augmented by the vertical movement of the vessel; and in the case of the wing boilers, lying near the bilge, the added vertical oscillation due to rolling may cause a still further increase. Also, as a result of the rolling, all of the weight of the boiler may be thrown on the upper part of the stools, on one side only, where, owing to their greater height, they may be less capable of supporting it. The stool plates vary in thickness from about $\frac{1}{2}$ inch for a small boiler to $\frac{3}{4}$ inch for a large, and they are stiffened all around by large double angles. They are made in two parts, for they are then more readily fitted, and the boiler is as well, if not better, supported.

With **ordinary floors**, the lower angles of the **boiler stools** are riveted to double reverse frames on the floors (Figs. 8 and 9, Plate 28). As these particular floors receive most, if not all, of the weight of the

boiler, they should evidently be thicker than the others, and their double reverse bars should be of the same large size as those on the boiler stools. The circumstance that the intermediate floors may take none of the weight of the boilers is a sufficient reason for making them stronger than those in the cargo holds; for when the vessel is at load draught, or if in the load condition she should take the ground, they might, having no weight above them, suffer a more severe upward bending stress. All the floors in the boiler room are, therefore, increased in thickness by $\frac{2}{20}$ inch, and their upper edges are provided with double reverse bars, the added one extending from top of bilge to top of bilge—except in small vessels. The increase in thickness is also particularly useful in providing a margin against corrosion (Art. 465). Instead of fitting double reverse bars, it would be better to fit one of greater thickness, for, as the comparatively thin double bars offer a large surface to corrosion, their strength may be rapidly reduced; directly under the boilers, where the heat is greatest, their horizontal flanges may waste away in a comparatively short period.

To prevent tripping of the stools, they are supported by fore-and-aft brackets, and by plates uniting their ends (Figs. 8 and 9, Plate 28). The latter, to be efficient, must be wide, but when so they may shut in, and prevent a proper circulation of air in the confined space below the boiler; this may be avoided by curving their upper edge, and when the lower one is fitted on the tops of the floors, they then not only support the stools, but distribute the weight of the boiler to the intermediate floors (Fig. 8). In some cases, where the latter effect is particularly desired, the boilers are supported, not by transverse stools, but by deep fore-and-aft bearer plates (Fig. 10), one on each side of the boiler, to take which they are provided with two or three special cast-iron attachments on their upper edge, and are held erect at these places by transverse bracket plates to the floors. In large vessels the floors which take the boiler stools may be increased in depth to about the level of the centre keelson; they then form an excellent foundation and greatly strengthen the vessel's bottom; and the resulting elevated position of the boilers is advantageous in reducing the heating and corrosive effect on the bottom framework, and in giving a greater degree of safety should a large volume of water accumulate in the bilges (Art. 419). In American lake steamers the machinery is usually at the stern, and the curious plan is sometimes adopted of placing the boilers on a sort of lower-deck platform, thus saving space below for coal bunkers or cargo, and placing the boilers at a broader part of the hull. It has also the advantage of raising the vessel's centre of gravity when in light trim, an important matter in securing weatherly qualities in these broad beamed vessels.

When there is a **cellular double bottom,** the tank framework in the boiler room is increased in massiveness; the floors are provided with double reverse bars, and their thickness, as that of all other parts of the tank, is increased from $\frac{2}{20}$ to $\frac{3}{30}$ inch. The increased thickness is intended to serve as a margin against corrosion. The **boiler stools** may sit directly on the tank top, being riveted to double reverse bars on the floors, in which case the latter should be of a size to suit those on the boiler stools. It is well to increase the thickness of these particular floors, and, if the tank is deep, to stiffen them with vertical angles. The more usual plan is to provide a **foundation for the stools,** in the form of a transverse I-section beam, riveted to the tank top (Fig. 5, Plate 27, and Plate 109). In a McIntyre tank these are necessary to distribute the weight of the boilers over the various fore-and-aft tank girders. They are advantageous in that, should the fixture of the stools be delayed until the boilers are in place,

the riveting of them may not disturb the watertightness of the tank. When boilers are placed near the bilge, they cannot be lowered directly into their berth; they are lowered straight down through the central deck opening, and are then shoved athwartship on skids; and, of course, to permit of this, only the outer halves of each outer pair of stools may be fixed in the first instance. When placed very close to the bilge the outer stools may fall over the margin brackets, and in such cases these, or the lower parts of two suitably placed web frames, may be specially formed to act as stools. In some vessels the boiler stools are of cast iron, bolted direct to the tank top.

The **boilers** merely sit in their stools without attachment, the curved form of the bed preventing any transverse movement. To provide, however, against the effect of excessive rolling, **stays** (of round or flat iron) are led diagonally from the tops of the boiler (through the side bunker) to the vessel's side, and when there are two or more boilers abreast, they are stayed the one to the other. In the event of end-on collision, the momentum of a heavy boiler, when the vessel's motion is suddenly arrested, might cause it to jump forward, and to guard against this (a contingency which might cause fracture of the steam pipes and loss of life), **collision chocks** (termed "ramming chocks" in warships) are fitted, one at each end of the boiler (Fig. 8, Plate 28). These are merely vertical brackets, fixed to the tank top or floors, the upper corners of which overlap the face of the boiler. They are useful not only as regards the displacing effect of collision, but in preventing gradual fore-and-aft "*creeping*" movement of the boiler, due to long-continued expansion and contraction.

When the vessel's inner bottom is curved transversely, as in warships, special care is required in fitting the boiler stools. Sometimes the template moulds from which they are to be formed are rigged up in the ship, being suitably adjusted and levelled, so that when the stools are ultimately riveted in the same place the boilers may bear properly and occupy their designed position. The curved edge of the stools may be cut to the figured radius of the boiler, or from a template mould taken from the boiler itself. As a boiler is not always precisely round, the former method may not result in a perfect fit, in which case discrepancies are made good by inserting iron filling pieces between the stools and the shell of the boiler. Sometimes the curved angle bars of the stools are not fitted until the boiler is in place, so that the latter may take a solid bearing on the stool plates, and to permit of an accurate fit of the bars.

Art. 249. In order that the stokers may stand at a convenient height with regard to the furnaces, a raised **platform** is provided **in each stokehold** (Plates 108 and 109). With ordinary floors it may be from 2 to 4 feet above them, with a double bottom from 1 to 3 feet. The supporting framework of the platform is often constructed in a rough and ready fashion, with wood bearers, but in high-class work it is neatly and efficiently made with angle or tee bars. The platform is of chequered plates, malleable or cast, of small size, so that they may be readily lifted to overhaul the pipes lying below and clean the bilge space. It is important that they should form an intact surface, without crevices, so that small coal and ashes may not pass below to form mud with the bilge water and choke the pumps. To this end, therefore, it is usual to lay first a complete flooring of wood, upon which the plates may rest; and this has the further advantage that, should a large volume of water accumulate in the bilges or on the tank top, it may not (when, through rolling of the ship, it strikes the platform from below) so readily dislodge the plates. Should this happen—a not uncommon occurrence—the result might be serious, for quantities of coal and

ashes would be washed into the bilges and, by choking the pumps, prevent the removal of the water, which, continuing to accumulate, might extinguish the fires. Also, the violent dislodgment of the plates might injure the men or damage the numerous pipes of this region. A similar platform is provided in the engine room, and, at various heights, grating platforms, suitably arranged, with communicating ladders for access to the different parts of the engine. Similar gratings are also fitted over the stokehold at the different deck levels.

CHAPTER XIX.

Art. 250. The overhanging **stern,**[1] with the projecting side **quarters** or **buttocks,** is a feature common to all sea-going vessels. It is useful in providing deck space around the rudder-head for the tiller and steering gear (Fig. 3, Plate 35); it protects them and the steersman from the violence of the waves, and the rudder from contact with quay walls or other vessels. It also provides reserve buoyancy, so that large waves may not overwhelm the deck, but rather lift the vessel's stern; in this respect it is particularly necessary in sailing-ships, as a provision against the contingency known as **"pooping."** When caught in a hurricane, a sailing-ship may be compelled to run before the wind and waves, and it not infrequently happens that a large following wave, overtaking her, may fail to lift the stern above its crest, which, breaking on board, may sweep the deck with disastrous consequences. As a provision against this casualty, sailing-ships are always designed with a poop or raised quarter-deck, which places the deck at a safe height and increases the buoyancy of the after end. The **bow,** unlike the stern, meets the waves, and so the chance of their breaking on board is even more pronounced; but here there is no vulnerable steering gear, and in stormy weather no one need stand forward. A sufficiency of **lifting power** is secured here by giving a large upward sheer to the deck, two or three times as much as at the stern, and by providing a forecastle. A similar buoyant effect to that given by the overhanging buttocks is sometimes secured at the bow, by *flaring* the vessel's sides, *i.e.* curving them outwards near the gunwale, a design which, although resulting in a very bluff forecastle deck, need not affect the fineness of the waterlines below. In sailing-ships this formation, in conjunction with the usual cutwater stem, may give very considerable lifting power (Fig. 3, Plate 65). In Channel steamers, which may have to leave narrow and exposed harbours stern-first, the stern is sometimes formed like the bow (see Fig. 12, Plate 39). But here there is still, in effect, a projecting stern, for the sternpost and rudder-head are situated some distance from the extreme end, thus providing the necessary protection and housing for the tiller, etc.

On account of its overhanging disposition, the **framework of the stern** requires to be specially arranged, so that it may support its own weight and resist upward shocks from the waves (Figs. 1, 2, 3 and 4, Plate 33). The **transom frame** is the most important part; it has a deep floor plate, so connected—by the middle—to the top of the sternpost as to form a strong horizontal girder, most capable in supporting the overhanging quarters and stern. Lloyd's rules require the **transom floor** to be of the same thickness as an ordinary floor, and 50 per cent. deeper. In screw steamers two or three of the frames immediately before the transom step

[1] As used in its particular sense, the term "*stern*," designates that portion of the hull as seen in profile abaft the rudder post; the term "*counter*," that part of the stern below the knuckle moulding which is covered by the strakes of shell plating as they sweep aft from the buttocks or overhanging quarters.

upon the arch of the propeller frame, and these, in large vessels, are also provided with deep floor plates, so as to form subsidiary transoms (Plate 109). Abaft the transom the ordinary transverse system of framing is inapplicable, for much of the supported surface lies athwartship; a radial arrangement is, therefore, adopted (Fig. 1, Plate 33), for the frames, having then little bevel, are easily made, and are most efficient in their support. On account of their inclination to the keel line, they are termed "*cant or stern-frames.*" Their heels abut on the transom floor, connecting thereto by bracket plates; and their upper ends connect by radial beams to the transom beam (see Figs. 2 and 4). As the entire framework of the stern is suspended bracket-like from the after surface of the transom, it has a tendency to droop, or topple over backwards; against this, however, it is well held by the weather deck stringers and tie plates, and by the shell plating, the upper part of which, encircling it like a hoop, binds it to the hull proper. The long shallow sterns of large steam yachts are specially strengthened against the downward pull of their own weight and the upward shocks of the waves, by fore-and-aft web frames.

Lloyd's rules require the **cant frames** to be the same distance apart as the others, measured at the knuckle line. They are of angle bar of the usual frame size; so also are their beams, which, when the gunwale is rounded, may be in one piece with them. The brackets connecting them to the transom floor may be the full depth of this plate, but in large vessels the alternate ones, or all of them excepting two at the centre, may be made quite small. If large they may be lightened with large holes, and, if not flanged on their upper edges, are provided with a stiffening angle. The position of the top of the transom floor relatively to the second deck varies; it is usually above it (Fig. 2, Plate 33), but sometimes it is at the same level (Fig. 4), so that the deck plating may extend right out to the stern. In such case, to provide access abaft the transom for riveting the deck plating or shell, manholes must be punched in its floor (Fig. 3). A description of the laying off work and building of the stern will be found in Art. 529.

The **transom beam** should be pillared at the middle or at each side. When the *rudder trunk* extends to the weather deck, a vertical plate is sometimes fitted between the transom floor and beam (Fig. 2, Plate 33); this is useful in that, besides forming the forward part of the rudder trunk, it supports the deck and checks side-swaying tendencies. Sometimes the rudder post extends to the weather deck, and if well connected thereto it serves the same purpose. On account of the restricted space abaft the transom, the fitting of the rudder trunk is often a difficult matter, and to facilitate the work the **transom floor** is often **jointed on either side** of the post, the central part of which may be fitted after the trunk is in place (Fig. 3). Owing to the sharp curvature and inclination of the oxter or tuck plates, it is often a difficult matter to secure proper contact of the shell flange at the heel of the transom frame angles; thick tapered liners are often introduced, and as a result there is sometimes trouble from leaky rivets. To avoid this, it is well to cut short the heels of the transom frame angles, and fit a special heel piece, formed of a flanged plate, neatly smithed to the required shape as ascertained after the shell plating is in place.

Art. 251. In the early iron vessels the stem met the keel with a sharp elbow-like curve at the **fore-foot** (Fig. 3, Plate 26), the transverse sections being of an acute V form. Now, it is usual, except in full vessels, to adopt an easy curve, so as to cut away the sharp, knife-like fore-foot (Fig. 8), for not only is this an awkward part of the hull to construct, but, owing to its

small volume and its heaviness, it is prejudicial as regards cargo carrying power. In modern, full, cargo vessels the fore-foot is not cut away, and it is made very full and flat, so as to provide useful buoyancy. Being entirely submerged, a bluff fore-foot does not increase the vessel's resistance. With a given displacement, it is advantageous in that it permits of finer lines above, thus minimizing resistance. It has the disadvantage, however, of reducing the vessel's draught when in light trim, and increasing the intensity of wave-pounding action (Art. 108). In small sailing-ships the fore-foot is useful, for its side surface, by contributing lateral resistance, tends to reduce leeway. In some large steamers the fore-foot is very much cut away by an extensive rise in the keel line; but although the resulting flat fore-foot does not affect the vessel's resistance, it is then, as in the case of bluff cargo boats, particularly liable to receive damaging blows from the waves. Contrary to what is generally supposed, it appears from an experiment made by Mr. Hovgaard [1] that when moving at high speed the lateral resistance of the fore-foot may assist the turning power of the rudder.

Art. 252. There are two **types of bow**: the *straight* (Fig. 4, Plate 26), and the *clipper* (Fig. 5), the latter being also known as the "*fiddle* or *cutwater bow*." In nearly all steamers the former is adopted; it may be perfectly plumb, but very commonly it has a slight rake, so that when the vessel trims by the stern it may be nearly plumb. A modified form of cutwater bow, formerly common on the north-east coast of England, is shown in Fig. 2. All sailing-ships have a cutwater bow (Plates 62, 63, and 65), so also have yachts, and a few high-class mail steamers (Plate 108) in which a graceful appearance is desired. In sailing-ships it is advantageous in that it increases the length of the base-line of the sail area, and reduces the length of the bowsprit; it also confers additional lifting power, and increases the vessel's weatherly qualities.

As regards collision, it is a particularly useful formation, for as the cutwater is the first part to crush up, it forms a buffer, absorbing the energy of the collision, so that the stem below and the watertightness of the hull may be unaffected. It is also advantageous as regards the vessel struck, for the damage may be confined to the above-water part of the hull. As a contrast to its saving influence, the destructive power of the underwater spur, or ram bow, of a warship naturally suggests itself (Fig. 2, Plates 31 and 84). So great may be the usefulness of a cutwater bow in minimizing the serious effects of collision, that it is sometimes urged that its universal adoption should be made imperative. It is apt to be an inconvenience in docking, however, and is more costly than a straight bow, matters which are usually regarded as more important than its possible usefulness in the remote contingency of collision.

Art. 253. The **bow frames** of a straight-stemmed vessel do not differ from the others. As noticed in Art. 81, their greater bevel makes them less efficient in supporting the shell; as a rule this is not considered, but in some very bluff vessels they are canted, so as to lie square or nearly square to the shell. In a vessel having a cutwater stem, the frames which sit upon the cutwater form small triangles (see Fig. 3, Plate 65). Formerly the bowsprit of a sailing-vessel was always shipped right into the hull, for which purpose the forecastle deck stopped at a frame termed the "*knighthead*," situated a short distance from the end of the cutwater (Figs. 1 and 6, Plate 65). This frame forms a small triangular bulkhead, having a hole to pass the bowsprit and take the wedging. In some modern vessels the forecastle deck is carried at one level to the end of the cutwater, the bowsprit being riveted thereto (see Fig. 3).

[1] See *Engineering* for August 2, 1889.

Art. 254. The **sternpost** of a sailing-ship or paddle steamer is practically a vertical continuation of the bar keel; it forms, like the stem, a stiffening margin for the shell plating, but it has also, of course, the distinctive duty of holding the rudder (see Fig. 1, Plate 45). In size it is identical with the stem bar, this being practically the same as a bar keel. It extends to the top of the transom floor, to which it connects by a pair of large angle bars. It may be tapered from where it enters the hull to the top, by 25 per cent. in sectional area (Fig. 2, Plate 33). To simplify the forging, the keel portion, which is scarph-jointed with the keel, is made short; but, regarding the joint as a weak spot, Lloyd's rules specify that the after end of the scarph shall be at least one and a half frame spaces forward of the post. To form sockets for the "*rudder pintles*," projections termed "*gudgeons*" or "*braces*" are forged on the post.

Art. 255. In screw steamers the sternpost becomes a massive **stern or propeller-frame** (see Plates 40, 41, and 109). Here there are two posts, the *outer* or *rudder-post*, and the *inner*, *body*, or *propeller-post*. They are united above by the *arch* or *bridge-piece*, and below by the *sole-piece*. The propeller shaft passes through the inner post, which is enlarged or bossed to receive it; and the propeller works in the *aperture* between the two posts. The posts and other portions of the stern-frame are about twice as massive as the sternpost of a sailing-ship or paddle steamer; their breadth is practically the same, but their thickness or transverse dimension is twice as great. As regards the rudder-post and sole-piece, strength is essential because, unlike the sternpost of a sailing-ship, they receive no support from the shell plating; standing alone and unsupported, they must resist the side stresses induced by the rudder, and the side-bending forces which may be experienced by grounding, which tend to break the sole-piece at its junction with the inner post, and the rudder-post at its junction with the bridge-piece. As the rudder-post is exposed more particularly to stresses acting in an athwartship direction, its transverse dimension is evidently more important that its fore-and-aft one; and in view of this it is common to increase it, and correspondingly reduce the fore-and-aft dimension, making the post almost square in section. In the case of the inner post, massiveness is essential in order that it may form a sufficiently inert and rigid bearing for the propeller; and, generally, stiffness and strength are required throughout the whole frame, to check the vibrating effect of the propeller with its prejudicial tendency on the riveting.

By Lloyd's rules the two posts, the bridge, and the sole-piece are all of the same sectional area. By the rules of the British Corporation the rudder-post and upper part of the propeller-post are 15 per cent. lighter than the lower part of the propeller-post, the sole-piece being 30 per cent. heavier. The scantlings specified in Lloyd's rules are tabulated under the vessel's second numeral. Those specified by the British Corporation are tabulated under the vessel's length and depth; and they assume for each length of vessel a certain maximum speed; if this be exceeded heavier scantlings are required.

The upper part of the rudder-post, within the hull, tapers by about 50 per cent. The keel portion tapers into the keel, with which—if a bar keel—it connects by a scarph joint, the after end of which must be at least two and a half frame spaces forward of the foremost part of the propeller-post. In the case of the sole-piece, while its sectional area between the two posts is maintained, it may be flattened and correspondingly widened. This is advantageous in that it permits of the propeller being placed rather lower down, the greater submersion improving its efficiency. It also strengthens the sole-piece against side-bending stresses, but, to secure this

advantage, its transverse strength must be maintained at its junction with the inner-post, either by maintaining its breadth or sweeping it into the inner-post with a large fillet. In order that the sole-piece and rudder-post may not suffer pressure through docking or grounding, the former is often curved slightly upwards at the after end; in full cargo vessels the upward extension should be small, so as not to reduce largely the immersed area of the rudder when in light trim. The precise form of the propeller aperture varies; formerly the inner-post was made straight from top to bottom (Plate 77) now both ends are usually inclined towards the rudder-post (see Plates 40 and 41). This formation is advantageous in reducing the length of the sole-piece, and in strengthening it and the rudder-post against side-bending stresses and the vertical pressures due to grounding. It also dispenses with a distinct bridge-piece, and the frame generally is stronger, more compact, and more easily forged. The reduction in the size of the aperture has little appreciable effect on the efficiency of the propeller.

Art. 256. The **stern-frame** must be **thoroughly incorporated with the hull**, appropriately with its massiveness, and to check the vibrating and jarring tendency induced by the propeller. The effect of vibration is often observed (especially in large vessels) in the loosening or breaking of the rivets in the propeller-post, at and below the shaft. It is often particularly marked when the propeller has lost a blade, and the vessel, so disabled, has made a long run; in some cases practically all the rivets in the lower part of the propeller-post have broken or worked slack, also many of those in the adjoining shell plating (Art. 315). To give the necessary rigidity, the shell plates adjoining the post are increased in thickness, and, in vessels over 350 feet in length, Lloyd's rules now require the shell plates which take the post below the boss to be connected thereto by three rows of rivets instead of the usual two rows (Fig. 1, Plate 87). And, further, in vessels over 20,000 plating numeral, the propeller-post is extended into the hull, so as to connect with a transom floor plate; the lateral rigidity so secured is very useful, for as the shell plating, the only other connecting medium, lies fore and aft, its capabilities in this respect are naturally poor.

The position of the **bridge-piece**, or top of the propeller aperture, varies; it need not be higher than is necessary to clear the propeller, and to place it low down is advantageous, for the posts are then shorter and stronger. When so arranged, the sides of the hull above the arch may be quite flat and parallel, in which case, instead of forming them by an extension of the ordinary shell strakes, a flat plate, termed a "*tuck plate*," suitably flanged to take the shell, may be fitted on either side, as shown in Fig. 9, Plate 57. As a tuck plate does not form a continuously curved surface with the adjacent shell, it is somewhat unsightly; to dispense with it, therefore, and, at the same time, avoid a confined and inaccessible space within the hull, the arch of the stern-frame is raised well above the counter (Fig. 8). The confined interior space above the arch is usually filled with cement. In exceptional cases, where the stern-frame is a casting, it has two bridges (see Fig. 10). The upper one is placed in line with the run of the counter, its section being such that the shell plates may connect thereto without a sharp knuckle or flange. The second is placed just above the propeller, so as to strengthen the posts, and a tuck plate is fitted on either side, between the two bridges, to reduce the water disturbance and maintain the efficiency of the rudder; otherwise a filling of timber may be introduced.

The **junction of the stern-frame with a side-bar keel** is the same as for a bar keel, but the scarph is longer and has three steps (Plate 38). With a flat-plate keel, the aftermost plates assume, in section, a trough-like

form, and the stern-frame is enlarged to fill the trough (see Fig. 1, Plate 40). To avoid local weakness, the vertical-plate keel must overlap the end of the stern-frame, the two parts being connected by tap riveted angles (see Fig. 1, Plate 87). The above refers to a forged frame; when of cast steel, and of large size, the section of the part adjoining the flat keel may be of trough form; and to secure a connection with the vertical-plate keel, a fore-and-aft web may be cast upon it, as illustrated in Fig. 2.

Art. 257. In **twin-screw steamers** the **stern-frame** may be an L-shaped post, as in a sailing ship or paddle steamer (Figs. 3 and 4, Plate 35, and Plates 38 and 108). It is now common, however, to form it with an aperture as in a single screw (Fig. 2, Plate 87), so that the propellers may be placed closer together; for, when the sides of the hull intervene, it is found desirable, for the efficiency of the propellers, to allow a clearance of a foot or so. In some cases an aperture is introduced so that the propellers may be overlapped, and thus allow the shaft to be placed nearer the centre line (Fig. 1, Plate 36, and Plate 37). This is advantageous in that the bossed portion of the vessel's side is less extensive, the length of the propeller brackets is reduced, and the strength of all parts is increased. Further, should the vessel touch the ground and heel over, the propellers when close together are less likely to take contact therewith, and, being well under the quarter, are less liable to come in contact with quay walls or other vessels. Although the fact of the propellers overlapping appears to have little effect on their efficiency, it has been found advisable, in the later large twin-screw vessels, not to overlap them, on account of vibration. To clear the overlapping blades, the aperture must be wide fore-and-aft, but it may be smaller vertically than that of a single screw, for not only are the propellers of smaller diameter and well submerged, but it is only a small part of their peripheries that overlaps.

In ordinary merchant vessels the **keel** is usually maintained as **a straight line from stem to stern**, excepting, of course, the small upward curve at the fore-foot. In warships, on the other hand, it usually inclines upwards at the stern, and in some cases at the bow as well, for a considerable portion of the vessel's length, rising by many feet (see Fig. 2, Plate 31). This design is advantageous on account of the superior turning or manœuvring power which results, and of the reduction in weight due to the removal of parts of the hull—the *fore-foot* and *heel*—which contribute a less buoyant effect than their own weight, and which are awkward to construct. The lesser draught at the stern tends to reduce the immersed area of the rudder, but this may be maintained—and advantageously in the case of a twin screw—by increasing its fore-and-aft dimension (Art. 263). When the propellers overlap, and so require an aperture in the stern-frame, an extensive rise in the keel line would cause the sole-piece to foul the propellers, and so, in two or three large, modern, merchant vessels this is dispensed with altogether, the necessary aperture taking the form of an arched hollow in the keel line (see Fig. 3, Plate 31), the after part of the arch curving down to support the heel of the rudder.

Art. 258. Stern-frames, rudders, etc., may be **forged or cast.** A forging may be of steel or iron (usually it is of iron), but a casting, of course, is always of steel, unless it be for a sheathed vessel, when bronze is employed (Art. 470). Castings are generally cheaper than forgings, especially when of large size or of complicated form; they also tend to greater efficiency, for they permit of refinements and intricacies in the design impracticable in a forging. Small, simple sternposts, stern-frames, and rudders are often forged in the shipyard, from waste scrap-iron or steel. If large, they are more usually of cast steel, for while the cost of a

forging increases with its massiveness, the assurance of its soundness diminishes, the welded joints becoming less reliable. Nevertheless, forged material is still often preferred, especially in the case of rudder frames. The reason for this is that it is possible, by skilful and careful workmanship, to produce a forging of practically undoubted soundness, whereas in a casting there is always a considerable element of uncertainty, the circumstances on which its soundness depends being numerous (comprising subtle chemical and physical effects, and internal stresses due to shrinkage when cooling from an exceedingly high temperature) and not always under control; and in some cases defects (contraction flaws), unseen at the first, may develop through time, and necessitate the renewal of the casting. Comparing, however, in a general way, ship forgings with castings, there is little to choose between them as regards reliability. In the case of stern-frames and other parts of complex form (hollow and irregular in section, and having projecting webs and flanges), the use of cast steel alone permits of their adoption, intricacies in the design adding comparatively little to their cost (see Plates 36, 43, and Fig. 2, Plate 87). Various practical matters in connection with the manufacture of forgings and steel castings will be found in Arts. 563 and 571.

A **cast-steel stern-frame** does not usually differ much from a forging. The edges of the posts within the apertures are very commonly rounded, to reduce the water disturbance; especially in large vessels, where the posts may measure nearly a foot across. The sole-piece also may be rounded, forming an ellipse in section, or it may be strengthened transversely by a horizontal web (Fig. 4, Plate 41). The tops of the posts within the hull may have a flange to take the transom plates; and they, as well as the keel portion, may be of **trough section**, the latter having a **central web** to take the vertical keel (see Fig. 2, Plate 87); massiveness is not required in these parts, and the hollow section reduces weight and permits of short through rivets. The posts of the stern-frame of a single-screw vessel are usually solid; in that of a twin-screw certain parts of the posts may be of trough section (Fig. 1, Plate 36, and Fig. 2, Plate 87). A hollow section is advantageous in permitting of short through rivets; weight for weight, it gives stronger posts, the sides of which may be bevelled to conform with the run of the shell plating, thus increasing the transverse rigidity and simplifying the work of fitting the plates. If the stern-frame is of simple L form, a hollow section is similarly advantageous, and it permits of the breadth of the post being made equal to that of the rudder-stock, with little extra weight and with a valuable increase of lateral strength.

Art. 259. In several vessels recently constructed a complete departure has been made from the ordinary structural design as regards, among other things, the stern-frame and rudder.[1] The dead wood and lower part of the stern-frame are cut away (in the manner shown in Fig. 3, Plate 31), and the rudder is of balanced type. Excepting the body post in way of the propeller boss, the entire frame is composed of steel plates. The arch over the propeller is a U-section 1-inch steel plate, and the rudder post is a tube, 21 inches diameter, made from a 1-inch steel plate, its lower part having an internal doubling. The top of the tube forms a socket for the rudder pintle, a bush being fitted within it; there is only one pintle, and it takes the whole weight of the rudder (this is 15 tons, but there is a displacement of 5 tons). The lower end of the tube forms a pivot for the "heel" of the rudder, the latter having a socket—lined with white metal—

[1] S.S. *Ajax*, etc., of the *Ocean Steamship Co., Ltd.*, described and illustrated in a paper by Mr. Henry B. Wortley, *Trans. Institution of Naval Architects*, 1900.

which slips over it. The rudder is built of plates and bars, and its interior is accessible. Its head is a forging, in one with which is the pintle; and it connects to the body by a flange coupling, there being a small casting on the former, having a corresponding flange.

Art. 260. Although **stern-frames** of the largest size may be cast **in one piece** (Fig. 2, Plate 87), it is common to make them **in two**, scarph jointing them as shown in Fig. 1, Plate 36, and Plate 41. It may be necessary to do so to permit of the frame being sent by rail from the steel works to the shipyard. It may also prove useful in the ship, for should the lower part of the rudder post and the sole-piece be damaged or carried away (as sometimes happens), this part may be renewed without the costly work of disturbing the remainder. It is also advantageous as regards the casting work, for to cast in one piece so large a mass requires special care; the casting may be successfully run, but, owing to the excessive shrinkage while cooling, serious internal stresses may arise, difficult to contend with, and perhaps resulting in fracture or hidden flaws. And, further, there is always the chance of a casting proving defective; if in one piece, a local defect may necessitate the condemnation of the whole, involving, of course, a serious loss to the manufacturer; by making it in two or more parts, the magnitude of the risk is reduced. The scarph joints must be large and securely connected, otherwise the vibrating effect of the propeller might loosen them, with disastrous results. Lloyd's rules require their length and breadth to be, respectively, 3 and $1\frac{1}{2}$ times the breadth of the post. Their surfaces are, of course, carefully machined to secure perfect contact; and they are united by four rows of large rivets, those in the body post—excepting a few tack rivets—also taking the shell plating. Similar scarphs are sometimes adopted in forged frames; here they are advantageous in that they dispense with welds, which, as noticed in Art. 571, are apt, in large forgings, to be points of weakness. The stern-frame of a warship may be a casting of very complicated form; one of these is illustrated in Plate 43. Those of sheathed warships are of phosphor bronze.

Art. 261. The **stem** is practically a vertical continuation of a bar keel. Its duty is to give stiffness and massiveness to the bow; if the thin shell plating of either side met without the interposition of a thick bar, the knife-like edge, so formed, would have neither of these qualities; it might not even withstand the buffets of the waves; it would be torn across by mooring chains, and could not endure even gentle contact with quay walls or other craft. The introduction of a thick stem bar not only strengthens the bow by its own massiveness and power of distributing pressure, but, by separating the shell plating on either side, increases the lateral stiffness. When moving even at low speed, the momentum of so large a mass as a loaded vessel may be enormous; and so slender, in comparison, is the structure of the hull, that impacts, even of a gentle nature, are usually accompanied by deformation at the point of contact. The rigidity of the usual stem bar is sufficient to distribute the pressure that would arise through gentle contact with obstacles in dock, and, in its design, a sufficiency in this respect is the limit kept in view. Its capabilities in resisting impact depend greatly on the direction of the blow; if end-on, it may cut through the side of another vessel and suffer little or no deformation; if inclined, the bow may be shattered. But, of course, much depends on the efficiency of its backing up by internal breasthooks (Art. 106).

The **scantlings of a stem bar** are practically those of a bar keel. It usually tapers either in breadth or thickness from the load waterline upwards, its sectional area diminishing by about 25 per cent. This is

permissible because the upper part is well backed up by the decks; and it receives better lateral support from the shell plating, for, while below water the vessel's sides may be almost parallel, towards the top they converge more and more squarely. To reduce water disturbance the fore edge is slightly rounded, the edges of the shell plates being chamfered (Fig. 1, Plate 93).

In large vessels the **stem bar**, if it were in one piece right back to the straight part of the keel, would be inconveniently long; in such cases, therefore, it is **jointed** above or below the turn. An undue importance is sometimes attached to the jointing of the stem bar, it being urged that there should be no joint from the keel line to the upper extremity. But, regarding the stem as a stiffening bar, it is evident that a well-made scarph joint can have little prejudicial effect; in case of collision, resulting in distortion of the stem, it is often found that a scarph joint, though twisted and bent, has remained close. It is common, when repairing a bow damaged by collision, to renew only the damaged part of the stem, introducing a scarph joint at any point.

The **connection of the stem to a flat-plate keel** may be made in the manner already described for the stern-frame (Fig. 1, Plate 40). In high-class vessels, to avoid a clumsy **club-foot**, the lower part is formed of an independent **steel casting**, of trough section, suitably formed to the shape of the hull, and having a central web to take the vertical keel (see Fig. 3, Plate 34). In full cargo vessels the rectangular section of the stem bar is usually retained, the keel plate which connects to its lower end being formed with a groove-like hollow at its forward end to embrace about two feet of the lower edge, as shown in Fig. 1, Plate 34, and Fig. 1, Plate 10. In some cases a stout angle bar, bevelled to suit the shell plating, is riveted to each side of the stem, as shown in Fig. 2, Plate 34. In small, light-scantlinged, fine-lined steamers the lower part of the stem may be conveniently formed of a large angle bar, flattened out where it adjoins the plate keel, and closed gradually to where it is welded to the solid stem bar.

To strengthen the fore-foot against grounding pressures, it is important that the vertical-plate keel should overlap and connect to the lower end of the stem. As in the case of a bar keel, the stem bar may be of iron or steel, forged or rolled. Various practical matters in this connection are noticed in Art. 503.

Art. 262. In a single-screw steamer the propeller shaft passes through the massive stern-frame; in a twin-screw vessel a similar bearing is provided by the **propeller struts or brackets.** Until recently these were always of the two-leg form shown in Plate 35, but now, in large vessels, it is common to substitute a single horizontal bracket, as shown in Plates 36, 37 and 38. The former has the disadvantage of adding considerably to the vessel's resistance, and though the disposition of its legs is such that it forms naturally a very capable bearing, its saliency and incompactness expose it to damage from sunken wreckage or by grounding. The single-leg bracket is very compact; in passing through the water it adds little or nothing to the vessel's resistance, for it is not an isolated body, but forms the aftermost margin of the bossing, or fin-like projection of the hull (see Fig. 1, Plate 30, and Fig. 3, Plate 31). By reason of its horizontal disposition it is less efficient in supporting the weight of the shafting and propeller, for, acting as a beam, its material, unlike that of a strut, is not all equally effective. By a judicious design, however, ample strength may be secured; and, moreover, its load is less than that supported by a two-leg strut, for much of the weight of the shafting is taken by the

bossed frames and plating of the hull immediately before it (Figs. 1 to 5, Plate 30).

The legs of an **ordinary strut** are of oval or egg section (Fig. 4, Plate 35); the edge of large radius is turned forward, for the fluid resistance of a submerged body is least when the head is bluff and the tail fine. There is no precise rule or practice as to the scantlings or sectional area of the legs. As regards their duty in supporting the vertical load of the propeller and shafting, the sizes generally adopted provide a very large margin of strength; for, as the upper leg is only subject to tension, and the lower one to compression, their strength is directly proportional to their sectional area—or about 30 tons per square inch in the case of cast steel. Thus computed, the load a stout strut might carry is greatly in excess of the weight of the propeller and shaft; but, of course, the requirements of rigidity and strength against chance side pressures and the vibrating effects of the propeller, the shocks due to racing (when the propeller, revolving violently, is suddenly brought up), and the centrifugal forces resulting from the loss of a propeller blade, all demand massiveness greatly in excess of what a consideration merely of the weight supported might indicate as sufficient.

There are various methods of connecting the legs of the struts to the hull. The most simple, and the one usually adopted in small vessels, is to fix them to the stern-frame, suitably formed for the purpose (see Fig. 3, Plate 35). If placed forward of the post, the upper leg connects to the side of the hull (in small vessels) by a large palm, or by two large angles, as in Fig. 4. The reinforcement of the vessel's side depends on the size of the strut and how it falls with regard to decks or side stringers; in a very small low-powered vessel there may be none at all, but in others the shell plating and the frame angles in way of the palms are locally doubled, or a short, stiffening intercostal stringer or web frame may be introduced. In warships the upper leg pierces the shell, and connects within, by a large palm, to a thick foundation plate, suitably disposed in the same plane as the leg, and rigidly held by bracket plates or by the beams of an adjacent deck (see Fig. 1, Plate 35). And the keel portion of the stern-frame, if a casting, is formed with a web projecting on each side (see Fig. 1, Plate 35, and Plate 43). In large warships the lower leg usually connects to the hull well above the keel (see Fig. 2, Plate 35); for when so disposed the strut is not liable to be damaged by grounding, and, being less exposed, is not so likely to foul sunken wreckage, and, further, as the leg is shorter, its capabilities as a strut are improved. The palms are of large size, to take the numerous rivets necessary to ensure a large margin of strength against the jarring and vibrating effects to which they are exposed. Their surfaces are machined so as to secure the all-important feature of a close fit, and to ensure this the struts are put in place temporarily, so that any unfairness in the faying surfaces may be noted and corrected.

Propeller struts are almost invariably of cast steel, the pattern for the casting being shaped with precision, by trying it in place in the ship. As the casting may warp and depart from the precise form of the pattern, the hole cast in its bossed part must be small enough to leave an ample margin —1 or 2 inches—for the final boring, after erection, for the propeller tube. In large struts, to reduce the boring work, the middle portion of the hole may be cast of large diameter, so that it may not take contact with the tube (Fig. 1, Plate 36). In small vessels the struts may be of forged iron, and in some cases they are built up of three parts, the two legs and the boss, bolted or riveted together (see Fig. 3, Plate 35).

Horizontal propeller brackets are always of cast steel. They may

be cast in one piece (Plates 36 and 38), or the port and starboard brackets separately (Plate 37). The arms are of hollow V section with internal cross webs. The after edge may be curved horizontally to conform with the transverse curvature of the bossed part of the hull. The port and starboard brackets are alike, but, with overlapping propellers, the boss portion of one of them is longer (Fig. 3, Plate 31, and Plates 36 and 37). In a vessel having an aperture in the stern-frame, they usually connect to the forward post, suitably fashioned to receive them. When fitted separately they may be fixed to the sides of the post with cross, through bolts (Plate 37). When in one piece they pass through the hull, in front of the post, in which case they are fixed with fore-and-aft bolts (Plate 36). The latter plan is advantageous in that the bolts are not, as in the former case, subject to tensional stress, and as the shell plating above and below is united to the brackets and to the post abaft them by independent rivets, the rigidity of the fixture is greatly increased. The bolts are hove up with large nuts, and, of course, all faying surfaces are carefully machined. The struts are usually inclined downwards so that the bossing of the hull may be normal to the general transverse slope of the shell, and thus, while giving the necessary outreach, have the minimum projection. When there is no aperture in the stern-frame the brackets are usually made in one piece, and, to secure a thorough incorporation with the hull, are formed with a flange to take the shell plating, and with large transverse webs to take two or three of the vessel's floors, specially strengthened for the purpose (Plate 38). These brackets may be exceedingly large and massive.

CHAPTER XX.

Art. 263. A **rudder** consists essentially of two parts: the *body* or *blade*, and the *stock* or *main piece* (see Fig. 2, Plate 40). The former provides the necessary surface for the impinging action and side pressure of the water, and the latter forms the axis or shaft through which the turning force of the steering gear is transmitted to the body. The upper part of the main piece, where clear of the body, is termed the "*head*;" this part suffers the same torsional force throughout, and is, therefore, made of parallel diameter; from its junction with the body to its lower end, or heel, it is gradually relieved of the torsional stress, for it transmits it to the body, and, accordingly, this part is tapered, from 35 to 50 per cent. (in sectional area), according to the type of rudder. The main piece is pivoted to the stern-post by the *pintles*, which work in sockets termed "*gudgeons*" or "*braces*," projecting from the post.

When the rudder lies fore-and-aft, the water, flowing past it, causes no more pressure on one side than the other. When turned, so that one side is opposed to the stream, that side experiences an excess of pressure, which, of course, is the unbalanced force that—by pushing round the stern—causes the vessel to swerve from her course. The side pressure increases the more directly the rudder opposes itself to the fore-and-aft flow of the water, but although it is, therefore, greatest when the rudder is turned quite athwartship, its effect in giving a lateral push to the stern is not then at a maximum. The precise angle at which a rudder exercises its greatest steering effect varies in different vessels; it lies between 30 and 45 degrees, and in practice provision is usually made for rotation to the extent of 40 or 45 degrees on either side.

The water pressure experienced by the rudder is proportional to its area, but is little affected by its form or contour. On the other hand, the **torsional or twisting effect on the head** is greatly influenced by the form of the rudder; in one of *balanced* type, there may be none at all; in others it increases the more the area is spread out abaft the axis, for, of course, the water then acts at a greater leverage. The water pressure on a rudder depends, of course, on the vessel's speed; it is usually taken to vary as the square of the speed—an assumption only correct in the case of a completely submerged surface. It also depends on the angle of the rudder, but, as just seen, the maximum angle is practically the same in all vessels. In smooth water, the torsional stress on the rudder head depends, therefore, on the area of the rudder, the distance of the centre of gravity of the area from the centre of the pintles (in similar rudders this is a constant proportion of the breadth), and on the vessel's speed; consequently, if wave influences be neglected, the diameter of the rudder head would be properly decided by these matters alone, without reference to the vessel's size. In sea-going vessels, however, the most severe stresses are incurred in heavy weather, by blows from the waves, whose intensity may be little influenced by the vessel's speed, so that in deciding the size of the

rudder head practical experience is here the safest guide. Lloyd's rules state the diameters suitable for all sizes of vessels (as estimated by their second numeral), they vary from about 3 to 11 inches, and represent what experience has indicated as a safe minimum for ordinary sea-going vessels of moderate speed and having rudders of normal proportions. As the rudder head of a sailing-ship is not so severely tried as that of a steamer, it may be from $\frac{1}{2}$ to 1 inch smaller. The rudder of a steamer is likely to suffer more severe stresses than that of a sailing-ship, for it is usually of larger area; this being necessary because, while its efficiency may be increased by the back-wash of the propeller, it may be greatly reduced by the presence of the propeller when this is not in motion; and, further, steamers often make a passage when drawing very little water, in which case a large area in the lower part of the rudder is essential; and as they must navigate narrow, tortuous channels under their own steam, they require quick turning power. Under the latter circumstances a sailing-ship is in charge of a tug boat; and, when at sea, as she must accommodate herself to the wind and waves, her movements are slower and easier than those of a steamer.

In the case of a **high-speed steamer**, or one having a specially large rudder, it is evident that a **diameter of head** suitable for the rudder of an ordinary slow-going vessel of similar size might be quite inadequate. Accordingly, to provide for such, **Lloyd's** rules present a **formula,**[1] in which the vessel's speed, the rudder area, and its breadth are the governing factors; if exceptional, the diameter found by the formula will exceed that tabulated on the simple basis of the vessel's size, and is, of course, the appropriate one in that particular case. The formula assumes all rudders to have approximately similar contours. In Atlantic liners and warships having broad submerged rudders, and whose great speed, maintained in heavy weather, may cause excessive stresses on the rudder, the head may be of very large diameter, 19 inches or more.

The **form or contour of the rudders** usually adopted in merchant vessels does not vary greatly. The curve of the bow is usually symmetrical, or nearly so, about mid-depth; in many cases, however, the lower half is made fuller (Fig. 3, Plate 40), and in some cases the upper, so that the greater part of the area lies towards the bottom or top. As regards the effect on the steering or turning power of the rudder, it appears from an experiment made by Froude [2] that the lower part is more effective than the upper, so that, when superior turning power is desired, this, rather than the upper part, should be enlarged. The experiment was made with a model, whose rudder was divided into two equal portions, an upper and a lower, which were fixed at an angle of 30 degrees with each other; by towing the model with the rudder free, it was found that while the lower half lay at an angle of 10 degrees with the keel line, the upper lay at 20, showing the former to be the more effective. A greater fullness in the lower part has the advantage of maintaining the rudder area when the vessel is floating light. An increase in the area of the upper part may greatly augment the

[1] Diameter of head in inches $= \frac{1}{32}\sqrt{D \times b(2B - b) \times S^2}$

D = the vessel's draught in feet.
B = the greatest breadth of the rudder in inches, from centre of pintles to back of rudder.
b = greatest breadth from forward edge of main piece to back of rudder.
S = vessel's speed in knots.

[2] See Dr. Woolley's paper "*On Steering*" communicated to the *British Association* in 1875; and, for instructive information on steering action, see the *Report of the British Association for* 1876.

stresses which the rudder may experience, due to the fact that the upper part is exposed to blows from surface waves, whose straining effects are the most critical. While maintaining the same depth and area, and, therefore, the same turning effect on the ship, a rudder of rectangular form would suffer the least bending and torsional stress, for the moment or leverage of the water pressure is then at its smallest. A rectangular form is commonly adopted in light-draught steamers, and in large twin-screw ocean liners and warships, in which the rudder is shallow compared with the vessel's length (Fig. 8, Plate 39). In warships the rudder is entirely submerged, to secure under-water steering gear and to protect it as far as practicable from surface waves. In twin-screw vessels a broad rudder is advantageous, because, when put over to port or starboard, it passes well into the propeller-race, where the impinging effect of the rapidly flowing water gives it superior steering power. Screw steamers may, of course, be turned round even when without headway, by the pressure of the water as it is thrown aft or pulled forward against the rudder by the propeller.

Art. 264. The **rudder area** of merchant vessels is not decided by theoretical considerations; even in sister ships it may vary, and yet both may steer satisfactorily. Experience is relied on as the safest guide; a rudder found to give good results in any particular ship is used as a basis for others of similar size. The **turning effect of the rudder** in any particular ship depends on several circumstances, more or less variable, and whose precise influence is uncertain—on the length, draught, and trim of the ship, on the fineness or fullness of her after waterlines and on the form of her heel and fore-foot; it also depends on the distribution of the cargo; if all, for instance, were concentrated amidships, the vessel would be more sensitive and quicker in turning than if it were all stowed at the ends. Taking the rudder of a small ship as a basis, that of a large one is small in proportion to her dimensions, and smaller than a theoretical consideration of all the governing elements would indicate as proper; hence the familiar circumstance that a large vessel obeys the helm less smartly than a small one. In practice a deficiency in the size of the rudder may be little noticed, for it may be met by simply turning it through a larger angle than might otherwise be necessary, which, with powerful and quick-acting gear, is a circumstance of little importance, except, perhaps, at a critical moment, when a danger might be avoided by great rapidity in manœuvring. In many cases, when a rudder is found to be too small, the deficiency is made good by adding an extension piece to the existing blade. Although a rudder may be sufficiently large to give ample turning power at ordinary speeds, it may be insufficient at low speeds, and especially when in shallow water. In passing through the **Suez Canal**, for instance, the speed must be low, and yet, to avoid running ashore, it is important that the steering qualities should be good; accordingly, vessels which navigate the canal usually carry a detachable extension for the rudder, which may be readily affixed to the upper part of the bow (see Fig. 5, Plate 41).

Art. 265. In a **balanced rudder** (Fig. 11, Plate 39, and Plates 43 and 44) part of the surface is before the axis, so that the water pressure on this portion counterbalances that on the after part. If perfectly balanced, the rudder would remain stationary at any angle, without external restraint from the tiller. But a perfect balance is not obtainable, for if balanced for one angle it is not so for another. At an angle of 90 degrees, for instance, when the rudder is square to the impinging water, the axis, in a rectangular rudder, would be in the centre; for smaller angles it would be nearer the forward edge, and nearer and nearer the smaller the angle; thus at 40 degrees a balance would be secured if it were distant therefrom about

40 per cent. of the breadth of the rudder, and at 10 degrees when distant 25 per cent. This is due to the circumstance that, while the forward portion of the rudder meets an undisturbed fore-and-aft stream of water, the after part encounters the same water, but so thrown out of its normal course by the forward part that its impinging effect is less forcible.[1] In actual rudders the position of the axis varies; in cases where only a partial balance is sought only a small portion of the area may be placed before the axis; in warships one-third is the general allowance.

The **use of balanced rudders** is confined almost entirely to twin-screw warships, in which, to secure quick manœuvring power, it is essential that the rudder should be large and yet be easily and rapidly turned (one for a single-screw vessel, of turret-deck type, is shown Plate 44). If well balanced, then, however large its area, the force necessary to turn it is small; when first adopted only hand-steering gear was employed, and, consequently, its advantages were then enormous. Thus, in H.M.S. *Minotaur*, having an ordinary rudder, it took seventy-eight men one and a half minutes to turn it through 23 degrees; whereas in H.M.S. *Bellerophon*, having a balanced rudder of 25 per cent. greater area, and sailing at the same speed, it took only eight men twenty seconds to turn it through 37 degrees.[2] With the introduction of steam steering gear, the advantages of the balanced type of rudder became less pronounced. Thus, in the case of H.M.S. *Minotaur*, when her rudder was controlled by steam gear, it took two men only sixteen seconds to turn it through 35 degrees. Nevertheless, in warships, the advantages of a balanced rudder are still important, for the smaller force required to turn it permits of its being readily worked by hand should the steam gear become inoperative. Although, when steaming ahead, little or no force may be required to turn and hold a balanced rudder, it is not so when steaming astern; it then behaves much like a rudder of ordinary type; if it could be turned completely round, its characteristics would be unchanged. On account of this, the head of a balanced rudder is made little, if any, smaller than that of an ordinary one.

Art. 266. Of ordinary **rudders** there are **two distinct types**: the *side-plate* and the *centre or single-plate*. In the older, or side-plate variety (Figs. 2 and 3, Plate 40), the entire rudder is formed in outline by a solid frame, forged or cast, composed of the *main piece*, the *bow*, and the uniting *stays or arms;* and on either side of it there is riveted a thin plate. A single-plate rudder (Fig. 1, Plate 40, and Plates 41, 42, and 44) is formed of one thick plate, which is held to the main piece by arms projecting therefrom on either side of the plate.

Although, in a **side-plate rudder**, the plates are thin, they, nevertheless, contribute great strength and stiffness to the rudder. To appreciate their capabilities in this respect, imagine a rudder consisting of the stock and one side-plate only (Fig. 5, Plate 39); and suppose it to be held hard-over by the tiller, with a stream of water impinging upon it. It is at once evident that the thin, flexible plate would yield greatly to the water. If now a second plate be connected to the other side of the stock (Fig. 6), the first, in bending, would bear against it, and cause it to bend also. As the resistance is now that of two plates, the stiffness of the rudder would be doubled, but, poor in the first instance, it would still be very inferior. It will be observed that, as a result of the bending, the edges of the plates are no longer opposite each other, one of them has crept forward. If, now,

[1] This effect is strikingly illustrated in Professor Hele-Shaw's paper, "*Pressure due to flow round submerged surfaces*," *Trans. Institution of Naval Architects*, 1900.

[2] See Sir W. H. White's "*Naval Architecture*," page 666.

this sliding movement were prevented, the conditions would at once be so altered as enormously to increase the strength and stiffness. The desired effect might be secured by riveting the marginal parts of the plates directly together, or, better, by interposing a distance piece, such as is formed by the rudder bow (Fig. 7). When so arranged the plates, being no longer independent, can have no relative sliding movement, the one still tends to creep forward on the other; but to do so it must pull the distance piece, or bow, with it, and thus compress or buckle the other plate; and if this did not buckle, the pulling plate, in endeavouring to make it do so, would stretch—that is to say, while the one plate would suffer tension, the other would suffer compression. It is evident, therefore, that the resistance offered by the rudder to side bending would now be of quite a different character to that which it offered when the plates were detached; then it was measured by that of two thin plates to lateral bending, but now by their resistance to stretching or compressing as a whole.

If the plates were united only by the bow and stock, they might, under excessive stress, fail to co-operate, for the one which suffered compression might collapse against the other, when, of course, their resistance would again become that of two detached plates. In practice this is prevented by the horizontal arms fitted at intervals between the main piece and bow. The strengthening effect of the side plates is proportional to the distance between them, and their stiffening effect as the square of such distance—that is to say, if the stock and bow were twice as thick, transversely, the same plates would have double the strengthening, and four times the stiffening effect.

It is not, of course, the side plates alone that constitute the strength of the rudder, for the massive frame itself may be capable of giving all the required resistance. The turning effect of the tiller is transmitted down the stock, and, of course, much of it is conveyed to the body of the rudder by the bow and radial arms; but as the plates are on the outside, they receive the brunt of the bending stress, just as the upper and lower layers of a loaded beam are the most strained and the first to fail. Their capabilities, however, are often greatly prejudiced by insufficient or defective riveting, for they are only held to the bow and stock by a single row of rivets, and these are sometimes unsound, due to the holes in the plates not being coincident with those in the forging, or to the rivets being insufficiently staved up to fill the holes in the latter. The liability of the rudder rivets to loosen is constantly observed; it is due, of course, to the severe stresses affecting them, coupled, in many cases, with their own defectiveness. Those in the middle of the bow are usually the first to fail, for here the pushing and pulling effect of the plates is most intense; when many consecutive rivets have loosened, the frame, being deprived of the strengthening effect of the plates, is very apt to break in the bow or arms. In large rudders the plates are now often connected to the bow and stock by a double row of rivets, thus ensuring ample strength.

Art. 267. In a **single-plate rudder** (Plate 41) the plate is from two to three times as thick as those of a side-plate rudder, varying from $\frac{1}{2}$ inch in a small vessel to $1\frac{1}{4}$ inch in the largest. As the plate has no direct connection with the stock, it is evident that the torsional force of the latter can only be conveyed to it by the arms; they alone turn it, and hold it against the impinging water. This circumstance constitutes a very important difference between the centre and side-plate type of rudder; in the latter the two plates give substantial assistance to the frame; in the former the plate only acts under the impulse of the arms. Here, therefore, the latter have a special duty, for which, owing to their comparative thinness,

they are not naturally well fitted. They receive considerable stiffness from the plate, but no strength, for at their root, where they adjoin the stock, the plate stops short. In the earlier rudders of this type much trouble was experienced through breaking of the arms (at the root) and, in some cases, of the main piece itself. A further source of weakness is the lateral flexibility of the body of the rudder; should the top portion be struck by a wave, for instance, it might not receive a prompt assistance from the lower part, and, alone resisting, might be severely strained.

The **frame of a single-plate rudder** may be **solid**, *i.e.* forged or cast with the arms in one with the main piece (Fig. 1, Plate 40, and Fig. 4, Plate 41), or it may be **built of separate pieces**, forged or cast (Fig. 1, Plate 42). In the latter case the main piece is usually a forged shaft, tapered towards the heel, and jointed to a separate head. It is turned parallel in way of the arms, which are bored with precision, shrunk on, and fixed against rotation by a key; and it has a longitudinal groove, which takes the edge of the plate, and also serves as key-way for the arms. This type of rudder is superior in that it is very reliable, for it is composed of simple forgings, there are no welds, and as the arms may be made very thick at the root (in a solid frame their thickness is rather less than half the thickness of the main piece) they are strong, and when well put together the rigidity of their fixture is permanent. On account of the greater strength of the arms, Lloyd's rules permit of their being placed about twice as far apart as those in a solid frame, thus giving about half the number, but the plate (in the case of small rudders) must be thicker, to compensate for the less uniform distribution of the support.

Lloyd's rules provide a table giving the dimensions of every part of single-plate rudders, both solid and built. In the former (Fig. 1, Plate 40) the arms are strengthened at the root by increasing their breadth by large fillets (having a radius at least one-fifth the distance between the arms). To strengthen them against side bending it would be better, of course, to increase their thickness rather than their breadth; and in some cases this is done, the forward edge of the plate being notched so that the roots of the arms may extend through it. In the built type of rudder there is always a groove in the main piece to take the edge of the plate, its depth being equal to the thickness of the latter. In the solid type this may be dispensed with, if—according to Lloyd's rules—the fillets of the arms are made so large as to meet one another, so that the entire edge of the plate may be supported on one side or the other (Fig. 4, Plate 41). Of course, although a groove does little to increase the torsional strength of the rudder, it may, if the plate fits tightly therein, confer considerable stiffness to the main piece, and relieve the arms, at the root, of shearing stress. The rivets connecting the plate to the arms are liable to severe stress, for not only do they suffer shearing forces due to the bending action of the water (the plate and arms tending to slide upon each other), but to endwise tension through the water pressure tending to force the plate and the arms asunder. They sometimes become loose, but this may be due, in great measure, to their being defective in the first instance, their shanks not properly filling the holes, or to the surface of the rigid arms not faying in proper frictional contact with that of the plate. On account of this, Lloyd's rules now require that the rivets in single-plate rudders shall be the same size as those in the stern-frame (Art. 291). In some later large rudders of this type the arms are made sufficiently broad to take two rows of rivets, and in some very large rudders the strength is increased by a projecting web, making them of T section. The lateral rigidity of the body of the rudder depends much on the thickness of the plate, in some of the earlier rudders

this was insufficient. To secure a maximum of stiffness in the stock, it is not tapered so much towards the heel as that of a side-plate rudder; in the latter the taper amounts to about 50 per cent. in sectional area, and in the former 35 or 45 per cent., according as the frame is solid or built.

Comparing the side-plate, with the single-plate type of rudder, the principal advantage of the latter is that it has no inaccessible interior, and is little affected by wear and tear. It may be observed that although many of the earlier rudders of this type proved weak, those now constructed are perfectly strong, the sizes of the various parts being much greater than formerly. In a side-plate rudder the effect of corrosion sooner or later demands repairs, re-riveting or renewal of the plates; but if the riveting is sound and sufficient, and if the plates are substantial and are kept well coated, this may be postponed almost indefinitely. Weight for weight, a side-plate rudder has the advantage of superior strength and rigidity, and it is less costly.

Art. 268. Another distinct type of rudder is formed of **one steel casting**—body and stock. To avoid irregular shrinkage, the body need not be provided with stiffening ribs, the necessary strength being secured by giving it ample thickness, especially towards the main piece. Such rudders are difficult to cast, especially when of large size, for the stresses set up in cooling are so severe that, if they do not fracture, they warp badly. They are advantageous in that, once cast, they are practically finished. They are suitable for small vessels, but have not, as yet, inspired much confidence. In some large, modern, ocean liners the rudder is of cast steel, in several segments, connected by horizontal flange couplings, the flanges giving great lateral strength and stiffness to the body.

Art. 269. Rudder frames, whether of side or centre-plate type, may either be **forged or cast.** When forged the different parts are made separately, and are then welded together; the usual **position of the welds** is shown in Fig. 4, Plate 39, and Fig. 2, Plate 40. In small rudders the stock may be forged in one piece, without welds; but when large the head portion is made separately, so that it may be conveniently turned; and it may then be either welded or **jointed by a coupling** to the remainder. In a cast-steel rudder the frame may be cast in one piece, but if large the head is cast separately, for the above reasons; and as cast steel is not welded, the two parts are united by a flange coupling. Several methods of arranging the couplings are shown in Fig. 4, Plate 39; Fig. 1, Plate 40; and Plates 41 and 42. The couplings shown in Figs. 7 and 8, Plate 42, permit of the lower part of the rudder being lifted—for repairing the pintles—without disturbing the tiller and steering gear. The flanges of the coupling are, of course, machined, so that their faces may fit accurately together, and, in the horizontal variety, to relieve the bolts of the torsional force, a key-shaped projection is formed on one of the parts, and fits in a groove in the other, but more usually grooves are formed in both, and a key fixed in one of them by studs. The bolts, of course, are turned so as to fit accurately in their holes. Their combined sectional area may be less than that of the rudder head, for, owing to their distance from the axis of the latter, their leverage or moment of resistance is greater than that of the material of the head. Although a well-fitted locking key greatly assists the bolts, the circumstance is regarded rather as a means of increasing the rigidity and security of the joint than as one permitting of a reduction in the size or number of the bolts.

In casting the frame of a side-plate rudder, the **bow** is a source of trouble, for, being slender, it cools more rapidly than the stock, and so, by contracting at an earlier period, tends to pull the stock—still hot and soft—

out of line. To avoid this, one or two breaks or openings are introduced in the bow, its continuity being made good subsequently by neatly fitted scarphing pieces (Plate 43); and projecting lugs may be cast on the bow to ensure a good connection (see Fig. 4, Plate 40).

Art. 270. The **side plates** should be in one length; but when large plates are not obtainable, they may be butt-jointed in the middle, on one of the arms, increased in breadth to take the two rows of rivets. A butted joint is objectionable, however, for, as it is rapidly affected by corrosion, it soon becomes an open crevice. The rudder is peculiarly subject to **corrosion**, particularly in screw steamers, owing to the back-wash of the propeller. A similar effect is observed in the honeycombing of the back surface of iron or steel propeller blades; here it is remarkable, but as yet its precise cause is not properly understood. The rivets are the first to suffer, their heads and points rapidly disappearing; to minimize the evil, the holes in the plates are countersunk and the heads and points left full. Lloyd's rules require the rivets in side-plate rudders to be the same diameter as those in the thick garboard plates, and to be spaced 5 diameters apart. The plates, if not well coated, also corrode rapidly, especially at their margins; they should, therefore, be substantial; Lloyd's rules require them to be of the same thickness as the lower plates of the bulkheads. Formerly the after edges of the plates were extended so as to project 2 or 3 inches beyond the bow; this was thought to have a steadying influence on the rudder, and to check side jarring.

The **rudder is carefully caulked**, so that water may not enter and set up internal corrosion, but in most cases this measure is ineffectual, for the inevitable corrosion of the rivets and plate edges soon provides an entrance. To minimize the evil, it was formerly the invariable practice to **fill the interior** with water-excluding material; sometimes wood was employed, otherwise a concrete of portland cement and coke, or tar and coke. Now, fillings are often dispensed with. When adopted, the material should be so dense and well packed as to exclude all water, and it should be light, so as to minimize the weight and friction of the rudder. Wood is objectionable, for it is liable to decay; cement or tar concretes are permanent, and have an anti-corrosive influence on the plates. To fill the rudder, it is laid on its side with the lower plate in place, the upper one being put on subsequently. Sometimes, in order thoroughly to fill the interior, cement or tar is injected by a force pump through a hole in the plating. If wood is employed, it should be well bedded in red lead.

Art. 271. In a **single-plate rudder** in which the frame is a forging, the **groove**—if there is one—may be machined in the stock before the arms are welded on, in which case a good fit for the plate may be secured. If a casting, the groove is cast in the main piece, and, not being subsequently machined, the fit of the plate is usually imperfect. Sometimes considerable difficulty is experienced in introducing the plate between the arms, and its forward edge into the groove, owing to the arms not lying perfectly fair, in two parallel planes, or to the edge of the plate being twisted as regards the groove. To force it into place, rigging screws are employed, and, as a result, the rudder-stock may be strained and distorted, thus throwing the pintles out of line. To avoid this, the groove—if not dispensed with—is usually made an easy fit for the plate, tightness being secured afterwards by caulking; in this case, however, it is evident that its usefulness in stiffening the stock disappears in great measure.

Art. 272. The **rudder pintles** should be strong and numerous, for they alone hold the rudder against side shocks from the waves; if weak, or few in number, they would be unduly strained, and might fracture, become

loose, or suffer rapid wear; also, the stock, when held only at wide intervals, might be insufficiently supported. Their diameter is usually half that of the rudder-head, their distance apart varying from 4 feet in a small rudder to $6\frac{1}{2}$ feet in a large one. As they form unyielding points in the stock, it is here that the arms of the rudder-frame should be placed. The uppermost pintle should be placed as high as possible (but not so high as to prejudice the strength of the frame at the junction of the head and body), so as to reduce the length of the unsupported rudder-head. This has a bearing at the upper deck, but the distance from here to the first pintle may be very considerable, and though the head suffers no side stresses, its great length between bearings would reduce its efficiency under intense torsional stress. In large vessels there is often an intermediate bearing at the top of the transom floor, and in some cases a band is fitted around the head just below the counter.

It is very important that the **pintles** and the holes in the sternpost gudgeons should be **precisely in line** with one another. If unfair, then as one or two of the pintles would press constantly on one side of the gudgeons, they would soon wear oval, and, at the same time, wear oval the gudgeon-holes. Also, alone taking contact, they might, should the rudder be struck by a heavy sea, suffer excessive stress; not infrequently they are broken from this cause. The holes in the rudder gudgeons are usually bored before the stern-frame is erected. Formerly, in the case of sailing-ships, they were bored after the post was erected and the shell plating riveted to it, the centres of the holes being accurately lined off by a stretched wire and sights. This practice was adopted in order to avoid the chance of the holes being thrown out of line by twisting of the post during the riveting operation. If the post is a casting, the holes in the gudgeons are cast about $\frac{1}{2}$ inch smaller than the finished size, being enlarged subsequently by a long boring bar and cutter, the bar passing through the holes and being accurately adjusted in line.

Formerly the **pintles** were always "**solid,**" *i.e.* they were forged in one with the rudder-frame (Fig. 2, Plate 40); but now, except in small rudders, they are practically always "**fitted**" as separate parts (Fig. 3). Fitted pintles are superior, in that they may be accurately turned, and be readily renewed should they break or become worn. The solid pintles of an old vessel usually require renewal at some time or other, on account of excessive wear; the somewhat clumsy method of doing so is shown in Fig. 5. When constructing a rudder with solid pintles, the latter are usually chipped into cylindrical form by hand, so that their accuracy of form is necessarily inferior. Solid pintles have the advantage of never working slack, and, if originally in line and well bushed, they are perfectly efficient.

Fitted pintles must be fixed with absolute tightness, otherwise the long-continued jarring would soon loosen them. There are two methods of fixture—the **cylindrical** and the **tapered.** In the former (Fig. 3, Plate 39), the hole in the *snug* (*i.e.* the projection provided on the rudder stock) is bored a tight fit for the pintle, which is then driven in until its shoulder bears on the snug, its upper end being clenched around the edge. Otherwise, instead of driving them up, they may be shrunk in, the snugs being heated to enlarge the holes sufficiently to take the pintles (which are made a size large), when, of course, the subsequent contraction nips them with immense tightness. If the holes are accurately bored, with a smooth surface, shrunk-in pintles cannot work slack, but, of course, they cannot readily be taken out for re-turning, re-bushing, or renewal. To permit of this, it is usual to taper the pintles, and heave them up in tapered

snug-holes by a nut on their upper end, which, when tight, is locked against turning by a small tap bolt or cotter pin (see Fig. 1). The taper of the pintle might permit of its being tightened should it at any time become loose, but as looseness is usually accompanied by ovaling or wear of the snug-hole, tightness so secured would not be permanent; when a pintle becomes loose, therefore, it should be withdrawn, the hole faired up, and the pintle re-turned or renewed.

In many vessels the **pintles** work in the gudgeons "*iron-to-iron*;" in which case **friction and corrosion** gradually result in a **loose fit**, the pintle becoming small and the gudgeon-hole large. When so loose that there is considerable play, say ¼ inch or more, the rudder might jar with such violence as to prejudice the steering gear, and cause excessive wear and tear, or perhaps fracture, of the pintles. In such cases, therefore, a **steel bush** is fitted in each gudgeon-hole (Fig. 1, Plate 39, and Fig. 2, Plate 41). Owing to the side pressure of the rudder, the pintles and gudgeon-holes usually wear oval, and it is no easy matter to bush them so that they may again fit accurately, cylindrical pintles in cylindrical holes, each one taking a proper bearing at all angles of the rudder. To do so, the rudder must be lifted; the pintles may then be chipped into cylindrical form, or else a liner may be fitted tightly upon them, then removed and its outer surface turned in the lathe, a bush being fitted and turned in a similar way for the gudgeon-holes. As a rule, little attempt is made to secure such accuracy, the chief aim being to stop the side play, with its jarring and damaging effects. Sometimes, without lifting the rudder, molten *white metal* is poured into the gudgeons around the pintles; if these are in line and cylindrical, this makes a capital bushing; but if oval or untrue, the turning of the rudder at once destroys the soft white metal.

In order that wear of the pintles may be readily corrected, the gudgeon holes are now very commonly bushed in the first instance, and the pintles encased in a liner; should these wear, they may be readily renewed, and with accuracy of fit, for the pintles themselves, and the gudgeon-holes, remain cylindrical. In most cases, however, only the one part, the gudgeons, are treated in this way (Fig. 2, Plate 41). In high-class work the pintles are covered with a **brass liner**, and the gudgeon-holes bushed with **lignum vitæ** (Fig. 6, Plate 42). The lignum vitæ may be turned from a solid block, or fitted in staves, so as to jam in the gudgeons; or it may be fitted in strips, in a brass bush. When carefully fitted, pintles having lignum-vitæ bushes may work without slackness for a very long time; should the wood wear, it may be readily renewed, and, if the bush is fitted from below (as shown in Fig. 6), without disturbing the rudder. When a brass liner is fitted over the pintles, care must be taken to prevent water entering the snug-hole alongside of the pintle, for, owing to the galvanic action set up by the brass, the faying surfaces might rapidly corrode and loosen the pintle. This effect is sometimes observed. In some cases the pintles are fixed in the gudgeons instead of in the rudder snugs, so that when it is required to bush them the bush may be conveniently introduced from above, without lifting the rudder.

Art. 273. In most rudders the whole **weight is taken by** the lowest or **heel pintle**, beneath which, to reduce the friction, a **disc of hardened steel** is introduced. When, in course of time, the disc or the end of the pintle wears, the resulting subsidence of the rudder would cause the snugs to take a bearing on the gudgeons; in such cases, therefore, the rudder is usually lifted and a thicker disc fitted. In order that this adjustment may be made without lifting the rudder, the disc is sometimes provided with a screwed shank, which, passing through the bottom of the gudgeon, may be

hove up as required. In heavy rudders, to reduce the friction and rapid wear, two or more of the pintles may be arranged to take a share of the weight, the holes in their particular gudgeons not being bored through. When, to avoid lifting the rudder, the gudgeon bushes are arranged to withdraw from below (see Fig. 6, Plate 42), this method of supporting the rudder is inapplicable; in which case the ordinary snugs may be arranged to bear upon their gudgeons, **annular discs of white metal** being introduced to take the wear and reduce friction (Fig. 6). This is an excellent method, and may be employed advantageously in all rudders. In some rudders the **pintles** have **conical ends**, which rest in correspondingly formed discs, each having a small axial hole to guide the pintles as they wear (see Fig. 2, Plate 39). By this formation side jarring of the rudder is prevented independently of the condition of the bushing; but as the pintles only take contact at the bottom, the side stresses, by acting on them with considerable leverage, may have a marked side-bending tendency, and may thus more readily loosen them; ordinary pintles bear in the gudgeons right up to their root, so that side stresses have a shearing rather than a bending effect; with strong, short pintles, however, it is an excellent plan.

In some vessels the **rudder** is **upborne from within the hull**. The bearing may take the form of two collars on the rudder head (Fig. 4, Plate 45), in way of the deck bearing, the latter being formed with a projecting annular flange to fit between the two collars, in such a way as not only to take the weight of the rudder, but to lock it against rising. For ordinary rudders there is little or no advantage in such internal support; a large bearing surface is secured, accessible for lubrication, but with steam steering gear the small friction of the rudder is not prejudicial. In the case of a **balanced rudder** such as is fitted in warships, an internal support may be necessary. In the rudder shown in Plate 43 there is only one pintle, at the heel; this takes no weight, the sole piece of the stern-frame in which it works being intended merely to hold it against side stresses, for which duty it is fitted by forming it as a flat web or horizontal fin. The **internal bearing** is here formed by an annular surface or flange on the bottom of the tiller or cross head, which rests on a corresponding surface S on the top of the sternpost. If the rudder is very heavy, conical roller bearings may be fitted between the surfaces, otherwise they merely slide upon one another, a projecting lip on the lower one serving to retain the lubricant. In the balanced rudder shown in Plate 44 there are three bearings, including the heel pintle, and the lower of the two bearings (a detail sketch of which is given) takes all the weight, or may share it with the heel.

Art. 274. The **rudder** must be held down, or **locked**, to prevent it from jumping up and perhaps unshipping itself. With fitted pintles the usual plan is to form one or two of them with a head on the lower end (these particular pintles being inserted after the rudder is shipped), which, should the rudder rise, takes contact with the bottom of the gudgeon (see Fig. 1, Plate 42). If, at any time, it is required to unship the rudder, it should be possible to do so without dry-docking the vessel; for in foreign ports there may be no dock, and even if there were it might not be possible to unship the rudder, for when its heel was on the bottom of the dock its long head might still be within the hull (to meet such cases, some docks are provided with a deep hole or pit). Accordingly, with this in view, the **locking pintles** should evidently be the uppermost, so that they may be withdrawn when the vessel is floating at load draught; if below water, a diver would have to be employed. With solid or shrunk-in pintles, a small projecting bracket is bolted to the rudder stock, below the upper gudgeon, or to the sternpost above the upper rudder snug.

Otherwise, the space between the stock and the sternpost and the two upper pintles is filled by a piece of hard wood (held in place by cheek-plates bolted to the rudder stock), or by a single trough-section plate. In some rudders, to reduce the water disturbance, fillings are introduced in the vacant spaces between the pintles, but their upper ends should be cut short, all but that of the upper one, so that the rudder may be lifted without their removal.

Art. 275. If the **rudder,** when struck by a wave, were **free to swing round** (through a breakdown of the steering gear), it would, if it did not foul the propeller, be brought up by the stock jamming against the sternpost, and, as a result, its pintles might suffer severe stress—just as would the hinges of a door if swung open beyond a certain point. To provide against this, **stops** are fitted (see Fig. 4, Plate 41, and Figs. 2, 3, and 4, Plate 42). These are small projections, on the rudder stock and sternpost (one or the other, or both), the faces of which take contact when the rudder has reached its maximum angle. As they are very near the axis of the pintles, their stopping force is exerted with small leverage, and so they are naturally very inefficient in arresting forcible movement. Their arm or leverage—which measures their capabilities—is the distance squarely measured between a line perpendicular to the face of the stop and the central axis of the pintles (the distance AB, Figs. 2, 3, and 4, Plate 42). To secure the greatest leverage, therefore, it is evident that the **faces of the stops should be disposed radially to the pintles,** that they should extend well out transversely, and that they should be so formed that contact may occur towards the outer edge. These matters are often neglected; in some cases, as shown in Fig. 4, Plate 41, and Fig. 2, Plate 42, the face of the stop is almost tangential to the pintles, so that there is practically no leverage, the two surfaces taking contact by an indirect sliding or wedging movement, productive of the most intense side stress on the contiguous pintle. In some rudders the back of the flange coupling is designed to act as a stop (Fig. 1, Plate 40), but more usually they are placed in way of the snugs or gudgeons. Large rudders are generally provided with two pairs of stops, an upper and a lower, which minimizes the stresses on the pintles and distributes the twisting effect on the rudder.

In view of the inefficiency of rudder-post **stops,** it is usual to fit others **on deck,** in the form of a chock or bracket, securely bolted to plating on the beams, in such position that they may take contact, at the proper angle, with the tiller or quadrant. They are very effective, for they act with a long leverage and cause no stress on the pintles. They are arranged to stop the rudder before the rudder-post stops come into play, so that the latter serve merely as a safeguard against the remote contingency of fracture of the tiller or rudder head. It is well that the steering engine should be arranged to stop automatically before the rudder is brought up by the stops, otherwise the gear and the rudder head would be uselessly strained by the full power of the engine. Also, where a cushioning device is introduced between the engine and the rudder head (Art. 406), the difference between the hard-over angle of the engine and that of the stops should still provide play for the cushioning effect. As already noticed, the angle at which the rudder exerts the greatest steering effect on the ship is about 40 degs. Any movement beyond this would, therefore, not only be useless, but might prejudice the vessel's manœuvring qualities, owing to the longer period occupied in shifting the helm from the *hard-over* points; and further, the greater range of movement would involve a larger steering gear, quadrant, etc.

Art. 276. Balanced rudders, of the type illustrated in Plate 43, must be exceptionally strong, for, having no pintles between head and heel, they derive no support from the sternpost against lateral bending pressures, which, moreover, owing to the exceptionally large area of the rudder and the high speed of the vessel, may be specially severe. The frame is of cast steel, formed usually, as shown in Plate 43. The portion representing the stock is made very wide, so that it may withstand intense side stresses. The head also is large, for not only is it liable to severe torsional stress (when the vessel is steaming full speed astern), but it must form a perfectly rigid pivot, however intense the lateral forces tending to bend the rudder between head and heel. A balanced rudder commonly fitted in torpedo boats is shown in Fig. 11, Plate 39; the lower part extends below and forward of the rudder post, to which it is pivoted in the usual way. And another design adopted in some single-screw turret-deck steamers is shown in Plate 44.

Art. 277. Cross-channel paddle steamers which must go astern when entering or leaving narrow and exposed harbours, are usually provided with an **auxiliary rudder at the bow,** so that whether moving ahead or astern, their steering qualities may be maintained. It must not project like an ordinary rudder, for with the vessel steaming ahead at high speed, it could not endure the side shocks of the waves; it is, therefore, placed abaft the stem bar, being so formed as to maintain the fairness of the vessel's bow lines (see Fig. 12, Plate 39). The stock is of semi-circular section, fitting in a corresponding hollow in the post or hull abaft it; and the external stem bar forms a guard around its forward edge. In order that when steaming full speed ahead (when, of course, only the stern rudder is used) it may be kept securely amidships, a vertical locking bar is fitted in the hull over it, the lower end of which sockets in the upper part of the rudder, and which may be lifted from within as required. The rudder is controlled by a tiller and chains, the latter leading to independent hand or steam steering gear at the bow or on the bridge deck amidships. Some bow rudders are constructed of plates and bars, as shown in Figs. 9 and 10; but the later ones of this type have only a centre plate, and are built up on each side with teak wood.

Art. 278. To prevent water entering the hull where the **rudder** head pierces the counter, the **head is encased in a watertight tube,** termed the "**rudder casing,**" "**tube,**" or "**trunk.**" If this extended to the weather deck, then, of course, although water might pass up or down, it could not enter the hull (see Fig. 2, Plate 33, and Fig. 1, Plate 45). If a stuffing box were fitted on the counter plating around the rudder head, a tube might be dispensed with, but this is hardly feasible owing to the difficulty of access; in warships it is the usual plan, but here, of course, the design is different in many respects (Fig. 8, Plate 39, and Plate 43). The trunk must be considerably larger—fore and aft—than the rudder head, for when it is required to unship the rudder, it must be drawn backwards, so that its pintles may clear the gudgeons; as it need not be large at the top, it is usually tapered.

If the trunk terminates at the top of the transom floor, as is common, two **stuffing boxes** are required, one **at the top of the tube** to keep out sea water, and one around the rudder head where it pierces the weather deck (see Fig. 4, Plate 33, and Fig. 2, Plate 45). They not only act as stuffing boxes, but as bearings, holding the rudder head against the stresses induced by the one-sided pull of the tiller. They may be formed like an ordinary stuffing box, as shown at A, Fig. 2, and in Fig. 3, Plate 45, but when watertightness is not essential, the usual arrangement is that shown in

Fig. 5, or Fig. 6. Here there are two thick blocks of lignum-vitæ, or cast iron with lignum-vitæ face pieces, fitting segmentally around the rudder head, against which they are pressed by long tapered pins. They are made of cast iron, in halves, so that they may be readily removed should occasion arise to unship the rudder. It is evident that this arrangement is not watertight, but when the trunk extends to the upper deck, this is not necessary; it is only occasionally that the vessel buries her stern in the waves, and as the submersion is only momentary, the water has not time to drive out the contained air and rise in the trunk. To check its entry, an external plate collar, in halves, is usually tap bolted on the counter around the rudder head (Fig. 1). The trunk may be formed in different ways, circular or square, of one or more plates. It is usually riveted to the sides of the sternpost, its lower end connecting to the counter plating by a flange or bevelled angle bar, and its upper one to the deck plating or to a horizontal plate fitted at the level of the transom plate. The connection to the counter plating must be carefully made; sometimes the watertightness is imperfect, for, owing to the knuckle of the oxter plates, the sloping and irregular surface, and the restricted access, the fitting and caulking work is not easy; to secure tightness, soft packing is used, and in some cases the work is buried in Portland cement. To ensure good work, the central portion of the transom floor should be arranged as a separate part (Art. 250).

CHAPTER XXI.

Art. 279. For constructive purposes, steel or iron is in every respect superior to wood; the most distinguishing feature, however, is the facility with which the component parts may be united by **riveting**, and with such efficiency that the strength across the joints may be little, if at all, inferior to what it is elsewhere. In **jointing timber**, by scarphing and bolting, the efficiency of the connection is very poor; it is impossible to obtain, at the joints, strength or rigidity in any way representing that of the intact log, for, when subjected to stress, now tensile, now compressive, the soft wood gives way under the cutting pressure of the small, hard bolts, so that the parts may strain and slide over each other. On this account, not many of the various lengths composing the different parts of a wooden hull are directly connected; each frame, for instance, is composed of two timbers placed alongside, each of which is made up of short pieces, merely butt jointed; but as the joints of the one are placed midway between those of the other, the absolute weakness of either at its joints, is compensated by the full strength prevailing here in the other. As a rule only important parts, such as the keel, keelson, shelves etc., are jointed by scarphing and bolting, for as these stand alone, in large single logs, an unconnected joint would be a point of absolute weakness. The greater portion of the numerous minor fastenings in a wooden hull are in the form of treenails, *i.e.* cylindrical pegs of hard wood, from 1 to $1\frac{1}{2}$ inches diameter; these are better than bolts in that, not being so hard and small, they do not so readily cut into the wood, enlarge the holes, and work slack. They are apt to decay, however, which is a serious matter.

Art. 280. The method of **jointing angle bars** is shown in Figs. 7 and 8, Plate 47. The ordinary mode of connection is by a **bosom piece** (Fig. 7). In order that, when under a longitudinal pull there may be no weakness at the joint, the sectional area of the bosom piece should not be less than that of the bars connected, at the weakest spot in either, *i.e.* across the rivet holes; and the number of rivets connecting it to each bar should be such that their combined sectional area (or, more correctly, their shearing strength) is also not less than that of the bar. As the flanges of the bosom piece are narrower than those of the bar, and as its heel is cut away, it must be considerably thicker to secure the same sectional area; in practice, however, ordinary bosom pieces are not usually made any thicker than the bars connected, and, consequently, the tensile strength is smaller at the joint than elsewhere; but this is usually unimportant, for in most bars tensile strength is subsidiary to stiffness, the scantlings being in excess as regards the former. Lloyd's rules require at least six rivets in the end of each of the two bars connected, and, in keelson angles, that the bosom pieces shall not be shorter than two feet. In many cases, instead of fitting the joint piece in the bosom of the bar, it may be placed alongside, as a **back piece** (Fig. 8). This method is

advantageous in that it reduces the number of three-ply rivets, the back piece is more easily fitted, its scantlings may be the same as those of the bar, and its heel need not be removed.

The importance of high **efficiency** (*i.e.* a degree of strength approaching very nearly that of the intact bar) **in the end joints** of angle bars, etc., varies with the duty of the part. In some cases joint pieces may be omitted, as, for instance, when the bar serves merely as a corner angle, connecting parts of little or no structural importance (such as the sides of deck houses, or the double frame angles connecting bulkheads to the shell, decks, and double bottom, whose purpose is to secure rigidity and watertightness), or which are not subject to stresses requiring perfect continuity of strength. As regards watertightness, a well fitted joint may be caulked more readily when not covered by a bosom piece, and by its omission three-ply riveting is avoided. The joints of the upper-deck gunwale bar, amidships, in long vessels, should be specially efficient; the workmanship, as regards closeness of fit and fairness of the holes, should be perfect, the sectional area of the bosom piece should be equal to that of the gunwale bar, and the rivets should be sufficiently numerous to give the required shearing strength.

The **joints of bulb-angle bars**, such as are employed for the side stringers, etc., are also connected by angle bosom pieces (see Fig. 10, Plate 47). In the case of a stringer composed of a **bulb plate** and double angles, the joints of the former may be connected as shown in Figs. 11 and 12. When scarphed as in Fig. 11, Lloyd's rules require the length of the scarph to be twice the width of the bulb plate; this method involves tapered liners behind the angles, and requires the removal of part of the bulb. It is evident that in the joints of a keelson, or part subject to deflecting stress, the scarphed portion, whether it be strapped or lapped, should be long, for if short the leverage on the terminal rivets would be so great as readily to strain them; with the same number of rivets, their strength or moment of resistance to a deflecting force increases with the length of the scarph. When the bulb plate is jointed with a strap (see Fig. 12), this should, of course, be the full width of the same; and, to pass it over the vertical flange of the angle bar, it may either be joggled or a flush surface secured by fitting a liner. Sometimes only a narrow strap is fitted, on the portion of the bulb plate which is clear of the angle; this, of course, is improper, it is done under the impression that as the angle bars cover part of the butt, they serve the purpose of a strap for this portion, but, of course, a double duty is then imposed on them. In many cases, instead of fitting a thick single strap, it is preferred to fit two, of half thickness, one on either side; by placing the rivets in double shear, this makes a very efficient connection.

With regard to the **joints of the centre keelson**, those of the vertical plate are treble riveted, the ends being lapped or connected with double straps (Figs. 1 to 6, Plate 47). A lapped joint is the more simple; it involves tapered liners at each of the four angle bars (Fig. 1), but when a slotting machine is available, the plate may be tapered in way of the angles, as shown in Fig. 2. Sometimes, instead of tapering the plate, the portion in way of the angles is cut off (Fig. 6), but, as regards strength, this arrangement is not commendable. When the joints of the vertical plate are butted (Fig. 3), Lloyd's rules require the combined thickness of the two straps to be $\frac{6}{20}$ inch greater than that of the vertical plate. The straps may be joggled between the angle bars (Fig. 5), or liners may be introduced (Fig. 4); the latter plan is clumsy and makes all the rivets five-pliers. The joints of the covering plate are treble riveted, lapped or

strapped; and, in large keelsons, having wide angle bars, there should be four longitudinal rows of rivets.

Art. 281. If the various **end joints**[1] in the structure of a ship were not points of weakness, their **relative position**, whether close together or wide apart, would be unimportant, but as they are points of weakness, their disposition requires care and attention. In wood ships, where, as already seen, the joints are often absolutely weak, a long distance between contiguous ones, or a "**good shift**," as it is termed, is essential to the strength of the whole. In the early iron vessels, in which the plates and bars were short and the joints not so perfect as now, a sufficient shift, particularly amidships, where the maximum longitudinal stresses prevail, was often difficult to secure. In modern steel vessels, however, the various parts are usually of such length that so perfect a shift may be obtained as to render comparatively unimportant any inherent weakness in individual joints. Of course, in any particular combination of parts, the influence of the disposition of the joints on the strength of the whole varies much with the character and duties of the combination. In fore-and-aft parts, such as the shell plating (Figs. 3 and 4, Plate 46, and Plate 90), decks and keelsons, which are subject to longitudinal stresses, the joints—especially amidships—should be so well distributed that two or more may not combine to form one zigzag line of marked transverse weakness. On the other hand, in parts such as the transverse frames, bulkheads, etc., which are not subject to intense tensile stress, the disposition of the joints is much less important. Nevertheless, as a good shift is usually as easily obtained as a bad one, the securing of it should be studied in all parts, however subsidiary.

The **influence of the disposition of the joints on the strength** of a compound part such as the shell, may be readily appreciated by considering two conjoined strakes by themselves. First consider the case shown in Fig. 15, Plate 46, in which the two end joints, being unconnected, are absolutely weak. Here it is evident that the strength of the combination, however remote the joints, cannot exceed that of one plate; in order, however, that it may be even so much as this, there must be a sufficient number of *edge* rivets between the two joints. If there were only one, as shown in Fig. 16, its resistance to shearing would evidently represent the strength of the combination; if there were two, the strength would be doubled. It is clear, therefore, that to secure the maximum strength (which, with unconnected joints, is that of one plate), the number of intervening edge rivets must be such that their combined resistance to shearing is at least equal to the tensile strength of one intact plate. In Fig. 15, the sectional area of each plate (less that removed by one rivet hole) is 11 square inches, and as that of the 14 1-inch edge rivets is also 11 square inches, the strength of the combination is the same whether, when pulled asunder, the fracture goes straight across, as shown in Fig. 17, or, in seeking to avail itself of the weakness at the other joint, it shears the 14 rivets, as shown in Fig. 18. Observe that mere distance between the joints does not affect the strength; if the seam were double riveted it might be reduced by half, for there would still be the same number of intervening rivets.

The precise usefulness of an edge union, in increasing the strength of two parts which together resist tensile stress, is forcibly illustrated in Figs. 5 to 11, Plate 46, which depict two three-stranded ropes sustaining a single load. In Fig. 5 the ropes are intact, and it is evident that to bind them

[1] The term "*end joint*" signifies a cross joint of a longitudinal part, in contradistinction to a fore-and-aft seam, or *edge joint* (see Fig. 3, Plate 46).

together with a lashing (the lashing may be taken to represent edge riveting) would not increase the strength. In Fig. 6 each rope has a broken strand, here the strength is only four-sixths of what it was before, for there are only four intact strands in place of six; and, observe, that the strength would not be increased by placing the defective parts remote from each other. If, however, they are shifted clear of each other, as in Fig. 7, and the ropes between bound together by a lashing, the strength may at once be increased by 25 per cent., for now the two weak points are isolated, and at each one there are five instead of four intact strands. To secure this advantage, however, the lashing must be sufficiently strong; it must be at least as strong as the broken strand, or, in other words, its strength must be at least equal to the loss of strength at either defective place. If it were less strong, a fracture would find it easier to travel from the one weak point to the other, for although in doing so it would have to sever the lashing, the extra work so involved would be more than discounted by the lesser work to accomplish beyond. In Fig. 8 the two ropes, though broken, are held together by the lashing; here the greatest possible strength is that of one rope, and to secure it the lashing must evidently have at least that strength. In Fig. 9 one rope is severed, and in the other one strand only; here, as in the last case, the maximum strength is that of one rope, but the strength of the lashing need not exceed that of one strand (*i.e.* the loss of strength at the least defective place), for whether the combination broke as shown in Figs. 10 or 11, three strands, or their equivalent, would be severed in either case.

The above conclusions may be readily applied to the case of conjoined strakes of plating. In Figs. 12, 13, and 14 the conditions are similar to those prevailing in Figs. 5, 6, and 7 respectively. In Fig. 19 the weakness at line CC is absolute, that at line DD is represented by the diminution in the breadth of the plate, due to three 1-inch rivet holes, which in a 1-inch plate, is equal to 3 square inches of sectional area (the fourth hole may be neglected, for as it is one of a continuous fore-and-aft row it does not cause greater weakness at the butt than elsewhere). If now a fracture occurred straight across at C, as in Fig. 20, it would have 11 square inches of material to sever; if it occurred simultaneously at lines C and D, as in Fig. 21, it would only have 8 square inches to sever, and consequently this would be the actual mode of fracture. To compel a straight-across fracture at line C, four 1-inch rivets (having 3 square inches sectional area) would have to be introduced between lines C and D (as shown by the crosses), for then the strength, whether the fracture went straight across or zigzag, would be the same. Observe that the four edge rivets represent the loss of strength at the stronger of the two joints, and they would still be necessary if the strength of the other joint were increased; if, however, it were so much increased as to make it the stronger, fewer might suffice, for they need then only be equivalent to the smaller loss of strength at this—the stronger of the two joints.

Although, in the above theoretical case (of two conjoined parts, subject to tensile stress), the combined strength of the edge rivets between the joints need not exceed the loss of strength at the stronger joint, this conclusion does not apply to the structural parts of a ship. In the case of the shell plating, for instance, as there are numerous strakes, and as all are not affected simultaneously by the same tensile stress from end to end, a fracture would not necessarily begin at the weakest joint, as in the case just considered. If, for instance, strake A, in Fig. 19, were the sheer strake, then, having no strake above it, and being more severely tried than the strake B below, it would be the first to fail, and if it broke at line D it

is evident that, to prevent the fracture from taking a zigzag course *via* the weak joint at C, *i.e.* to compel it to travel straight down through the intact plate immediately below it, the number of edge rivets between C and D must be such as to give a shearing strength equal to the loss of strength at C; which, in the case illustrated, is the full strength of the plate. It is evident that with the same spacing of edge rivets, the weaker the joints the greater must be the fore-and-aft distance between them, and conversely, the stronger they are, the less the need for such remoteness; if as strong as the intact plate they might be placed in the same transverse line.

Art. 282. In different vessels the relative strengths (as regards the intact plate) of the various **shell joints** varies; for it depends on the thickness of the plates, the size, number, and material of the rivets. To ensure, therefore, that the joints may not, in any case, form a zigzag line of weakness, they should be placed systematically **as remote as practicable** from each other. Lloyd's rules, in this respect (see Fig. 3, Plate 46), require those in adjacent strakes to be at least two frame spaces apart, or about 4 feet, which, with treble-riveted end joints and double-riveted landing edges, more than discounts any likelihood of their forming a zigzag line of weakness. The **sheer strake**, being the upper margin of the shell, may be likened to the hem of a garment, any weak spot in which is, of course, a likely place for a tear; and as, from its position, remote from the neutral axis, it is more liable than any other part of the hull to severe tensional stress, it is evident that efficiency in its joints is of the utmost importance. In practice, therefore, while the joints below may, in small vessels, be double riveted, those of the sheer strake (except in the smallest vessels) are never less than treble riveted, and in large vessels double buttstraps may be employed, not only for the sheer strake, but for the strake below and for the deck stringer plate. And, further, where, as in small vessels, the landings of the different strakes may be single riveted, that of the sheer strake is always double; for, as just noticed, this minimizes the prejudicial effect of any inherent weakness in its joints, or in those of the strake below, for it compels a fracture, once begun, to travel straight down through the intact strake below, or, in other words, prevents it from availing itself of contiguous weak points in the strake below.

It should be observed that **all structural parts are necessarily weakened** against tensional stresses **by the various cross lines of rivet holes** required to bind them together and to the framework. The maximum strength of a strake of shell plating, for instance, is limited to its sectional area where reduced by a line of frame rivets, of deck plating where reduced by a line of beam rivets, and of keelsons and stringers where reduced by the rivets connecting them to the floors or frames. As ordinary frame rivets are spaced 7 diameters apart, they reduce the effective breadth of each strake by one-seventh, which means that the longitudinal strength of the entire shell at each frame is only 86 per cent. of what it is between them. The loss is really greater, for, owing to the material removed by the countersink of the holes, 86 becomes 81. With the usual rivet pitch, therefore, 81 per cent. represents the highest useful efficiency of the joints, and so to make them stronger would not be advantageous. In the case shown in Fig. 1, Plate 46, the strength of B strake at line D*d* is less than it is in line E*e*, for while in the former the rivets are spaced $3\frac{1}{2}$ diameters apart, in the latter they are 7 diameters; and in order, therefore, that a fracture, travelling down the frame, may not step back to D*d*, as in Fig. 2, and thus avail itself of the greater weakness in this line, the number of landing rivets between D and E and *d* and *e* must be such as to give a shearing strength at least equal to the tensile strength of the material

removed by the extra rivet holes in the joint; that is to say, the combined shearing strength of the landing rivets must be equal to the difference in the strength of B strake at the frame and at the joint. In Fig. 2, the zigzag fracture there shown necessitates the shearing of eight landing rivets.

The **lapped joints** of the shell plating are often placed so **close to the frames** that no landing rivets occur between them (see Fig. 2, Plate 51, and Art. 312). In these cases, therefore, as the outer row is, in effect, in one line with the frame rivets above and below, its weakening effect represents that of the frame line across this strake. And as the spacing of the frame rivets is 7 diameters, and those of the joints $3\frac{1}{2}$, the loss of strength in the line of frame rivets is doubled at this place. To secure the greatest theoretical efficiency against fore-and-aft tensional stress, the joints should evidently be placed, as nearly as practicable, midway between the weak frame lines.[1] In ordinary merchant vessels, however, a line of frame rivet holes cannot fairly be regarded as a line of weakness, *i.e.* of prejudicial weakness; for the thickness of the shell plating is assigned with such perforations in view, *i.e.* with the knowledge that only some six-sevenths of its sectional area is available against tensional stresses; and in modern steel ships, so large is the margin of strength that any local weakening effect due to the still greater perforation at contiguous joints does not seriously affect the strength of the hull as a whole. Nevertheless, it is evident that care should be taken not to place the joints of neighbouring strakes close to the same frame: Lloyd's rules (Fig. 3, Plate 46) require that there shall be at least two intact strakes between joints in the same frame space; and in most cases this minimum is exceeded (Fig. 4).

Art. 283. Notice now those matters which govern the **efficiency, or strength, of riveted joints.** Plates may be connected together either by a *lapped* or a *butted* joint (see Figs. 6 to 17, Plate 50). A butted joint, it will be observed, is practically three lapped ones, the buttstrap representing the third or intermediate plate. Formerly all end joints were butted; and so the term "*butt*" is often used in a general way to signify any end joint, the somewhat contradictory expression "*lapped butt*" meaning an overlapped end joint. In ordinary butted joints there is only one strap, but when special strength is required two are fitted, one on each side. Whatever the type of joint, the riveting may be *single*, *double*, *treble*, or *quadruple*; *i.e.* there may be one, two, three, or four cross rows of rivets in the end of each part connected—in rare cases five.

When strained to destruction, a joint may give way in three distinct ways, depending on the number and distribution of the rivets (see Plate 49). All the rivets in the end of one part may shear, the plates remaining intact (Figs. 4, 11, 18). One of the plates (or the connecting strap) may fracture across a line weakened by rivet holes (Figs. 2, 7, 14, 19, 21, 23, 26). Or the fracture may be a compound one, the plate breaking at a line rendered specially weak by rivet holes and shearing simultaneously some rivets in another line (Figs. 3, 8, 9, 10, 15, 16, 17, 24, and 27). It may be observed that fracture of a buttstrap is usually precluded by making it rather thicker than the plates.

Numerous **experiments** have been made from time to time to ascertain the relative efficiency of different methods of jointing, and to obtain precise information on various matters which might serve as a basis in designing and computing the **strength of joints** in future practice. It was required to ascertain the relative strengths of plates and rivets, and of steel

[1] For an interesting study of this subject, see Sir W. H. White's paper, *Trans. Institution of Naval Architects*, 1873; also Sir Nathaniel Barnaby's paper contributed to the same Society in 1866.

and iron rivets; the resistance which rivets of different size exercise against shearing, how this compares with their tensional strength, and whether it is affected by the shape of their head or point; also, to what extent, if any, joints riveted by hydraulic power are stronger than those riveted by hand. Further, it was desired to ascertain how, and to what extent, the strength of a plate between the rivet holes is prejudiced by punching or drilling; and the value of the restoring effect of countersinking the holes, and of annealing the plates. Also, to what extent all these matters are affected by the spacing and distribution of the rivets, or by the method of jointing, whether by a lap or by single or double buttstraps.

Some of the more important conclusions which these experiments established will now be noticed. It should be observed, however, that the results obtained by different, and even by the same, investigators often vary considerably, due to a number of causes; thus no two joints can be identical, the preparatory work of punching the plates and of riveting them together being one of no great nicety; then, in experiments apparently identical, there may exist differences in the conditions, which, although inappreciable, may have a commanding effect on the behaviour of the joint; the mechanical qualities of the material may not be the same, or they may undergo a change by the work of making the joints. In the following the general average results will be given.[1]

Art. 284. The **shearing strength of steel or iron rivets** is less than the tensile, by 15 to 20 per cent., and it is independent of the size of the rivet. Iron rivets are still extensively used; they are made of a specially good iron, having a tensile strength varying from 22 to 26 tons per square inch. Their shearing strength, unlike that of steel rivets, is fairly uniform; it varies, however, according as the plates connected are of steel or iron; it is greater in the latter, where it is about 19 tons per square inch; in the former it is some 14 per cent. less, or about $16\frac{1}{2}$ tons per square inch. The probable cause of the smaller strength in steel plates is that, as these are harder than iron plates, they bear upon the rivets with a more unyielding edge, a steel joint forming, in effect, a more efficient shears. The tensile strength of steel rivets varies from 26 to 30 tons per square inch, and their shearing strength may be taken as 22 or 24 tons per square inch; experiments, however, show it to vary considerably, a steel possessing high tensile strength sometimes giving comparatively poor results under shear.

Excepting single-riveted lap joints, the shearing strength of rivets is much the same in all joints. When a **lap joint** is **subjected to tensile stress**, the plates, originally in different planes, at once tend to place themselves in the same one, so as to lie in the direct line of stress (see Figs. 1 to 3, Plate 48). In the case of a single-riveted lap joint, owing to its narrowness, the **deformation** is considerable, and as the rivets are, therefore, subjected not only to shearing stress, but to endwise tension, they give a somewhat lower shearing strength. It is found that when the heads and points of the rivets are large they check the deformation of the joint, and result in a higher shearing strength. It will be observed from the sketches that the deformation diminishes with the breadth of the overlap.

A **strapped joint** also suffers **deformation** under stress, the plates and strap yielding laterally, so as to place the central part of the latter in the line of stress (see Figs. 4 to 6, Plate 48). The thicker the strap

[1] The experiments from which most of these are derived are those of Professor Kennedy, recorded in the *Proc. Institution of Mechanical Engineers*, 1885; Mr. Wildish and Mr. Martell, *Trans. Institution of Naval Architects*, 1885 and 1878; and *Merchant Shipping Experiments on Steel*, issued by the Board of Trade in 1881.

the smaller the deformation, if it were a thick slab there would be none. The shearing strength of the rivets in a strapped joint is much the same as in a lapped one, so long as the strap is rather thicker than the plates—in practice it usually is made thicker. In a double-strapped joint, excepting a slight lateral parting of the straps, there is no deformation under stress. Nevertheless, although the rivets are here in double shear (each one requires to be shorn across in two places before the joint parts), their strength is not quite doubled; Lloyd's rules for boilers, and those of the Board of Trade, credit them with only 75 per cent. greater strength than those in single shear.

Experiments indicate that the **shearing strength of rivets in drilled holes** is rather less than it is in punched ones, due to the sharper cutting edge of the former, and to the fact that the rivet shank (the part between the head and point), being perfectly cylindrical, elongates more readily, and so permits of a greater deformation of the joint.

Art. 285. If, in a steel plate, there are holes in the line of fracture, their mere presence affects the strength of the plate per square inch. Thus, the **tensile strength per square inch of a test piece** may be considerably **increased by drilling a hole in it** (Fig. 10, Plate 48); and a test piece having two half holes or notches in its edges, is stronger than one having the same minimum breadth throughout (Fig. 11). And, similarly, in the case of a wider test piece, the strength per square inch may be increased by drilling a line of holes across it. The increase is greater the more closely the holes are spaced, *i.e.* the smaller the pitch. It was found [1] that when the holes in a $\frac{3}{8}$-inch plate were 1·9 diameters apart, the gain in strength was 20 per cent.; at 2 diameters, 15 per cent.; at 3·6 diameters, 10 per cent.; and at 3·9 diameters, 6·6 per cent.; the gain was rather less in thicker plates. The precise cause of this augmentation is not perfectly understood, it is explained in a measure by the difference in the deformation of a test piece which results from any local variation in its sectional area. Thus, before a test piece breaks, it draws out, increasing in length by about 20 per cent., with, of course, a corresponding reduction both in breadth and thickness; and at the moment of fracture a very marked contraction occurs at the break, the metal flowing and shrinking inwards (see Fig. 11, Plate 99). A drilled test piece behaves differently; there is little preliminary stretch, that which occurs being located at the reduced part, alongside of the hole; and any contraction of sectional area which occurs at the moment of fracture is wholly confined to this place, and, as a weakening influence, is restrained or limited by the unshrinking full-width portions immediately above and below it. Ordinary iron plates gain little strength by the presence of drilled holes, for in this material there is little stretch and flow at the point of fracture.

Art. 286. The presence of **punched holes** has also a **strengthening influence,** but it is greatly lessened, and usually more than **discounted, by the injury** which the steel immediately around the holes suffers **from the crushing and rending action of the punch.** This effect of the punch may be demonstrated in various ways. If, in one of two similar test pieces cut from the same plate, a hole is punched, its strength per square inch may be 20 per cent. less than that of the other; and, similarly, with wide test pieces, or plates having a cross row of holes. The precise loss of strength varies with the thickness of the plate and the distance between the holes; in thin plates there may be no loss, but an increase; and, whatever the loss, it is lessened when the holes are placed closer together. In Kircaldy's experiments (*Merchant Shipping Experiments on Steel*), it was

[1] Professor Kennedy's experiments.

found that by punching $\frac{3}{4}$-inch holes, at 2-inch pitch, in a $\frac{1}{4}$-inch plate, the strength was increased by 1 per cent; when punched in a $\frac{1}{2}$-inch plate there was a loss of 6 per cent. With 1-inch holes, at 3-inch pitch, in a $\frac{3}{4}$-inch plate, the loss of strength was $17\frac{1}{2}$ per cent.; and in a 1-inch plate, 24 per cent. The milder the steel, the less is it affected by punching; a steel of 26 tons tensile strength is less susceptible to injury than one of 32 tons; and if of hard or inferior quality it may be rendered perfectly brittle and unreliable. Iron plates do not suffer so much nor in so variable a degree. When steel began to supersede iron, it was of uncertain and often of very inferior quality; and the injury which it suffered from the punch was often so pronounced as greatly to delay its general adoption.[1]

In **shearing a plate,** the pressure and rending **action of the knife** has a similar effect on the contiguous steel to that produced by the punch. In a tensile test piece, for instance, the edges must always be planed, for if the rough sheared edge were not removed its strength would be small and arbitrary, and it would snap in two with little or no elongation and contraction of area. As in the case of punching, the thicker the plate the more damaging the effect of the shears; it extends further into the plate, in test pieces 1 inch thick, for instance, it is found necessary to remove at least $\frac{1}{4}$ inch from the sheared edge.

This curious **effect of the punch or shears is explained** by the fact that the material around the holes, or contiguous to the edge, is rendered hard and brittle. If steel be worked cold (*i.e.* if it be rolled, hammered, bent, or twisted, so as to alter the molecular formation), while its strength will be increased by the process, its ductility will be reduced. Cold-drawn wire, for instance, may be many times stronger than the metal from which it is drawn, but it will be much less pliable or ductile. In punching a hole, the pressure of the punch, just before it begins to shear or force out the cylindrical punching, compresses the plate, not only in the direction of its own movement, but radially from the hole, due to the side swelling or flowing tendency of the material directly under the punch; and, further, as the punching is forced out, an effect akin to wire drawing is produced on the material at the edge of the hole. These causes combined produce the familiar effects of **cold working,** *i.e.* the material around the hole (in an annulus from about $\frac{1}{16}$ to $\frac{3}{16}$ inch thick, according as the plate is thin or thick) becomes stronger, but, at the same time, loses its ductility and becomes comparatively brittle. The thicker the plate the greater the pressure required of the punch or shears, and so the more marked the disturbing effect on the molecular arrangement of the steel; thin plates may be little affected, thick ones may be seriously impaired.

The fact that the damage done by the punch is due to the formation of a thin annulus of brittle metal may be readily demonstrated. Thus, if a hole punched in a test piece is rimered out to a rather larger diameter (say $\frac{1}{8}$ or $\frac{3}{16}$ inch larger), it will no longer cause a loss of strength; for the narrow zone of damaged material being removed, the hole will, in effect, be a drilled one, and it will then strengthen rather than weaken the test piece—per square inch, at the point of fracture. It is proved again by the fact that if a test piece, having a punched hole, is annealed, *i.e.* heated to redness and cooled, the hole will no longer have a prejudical effect; for, by the action of annealing, the original mechanical qualities of steel are restored, and consequently, in the

[1] Some of the peculiarities and defects of the early steel are described by Sir Nathaniel Barnaby in his papers, "*On the connection of plates of iron and steel in shipbuilding*," *Trans. Institution of Engineers and Shipbuilders in Scotland*, 1865–66; and "*On iron and steel for shipbuilding*," *Trans. Institution of Naval Architects*, 1875.

case of a punched test piece, the brittle annulus assumes its normal state. Some refined experiments were made by M. Barba;[1] by careful machining, he cut out, from around two holes, one punched and the other drilled, an annulus of metal $\frac{3}{16}$ inch thick. The one from the drilled hole was found to be perfectly ductile, it could be collapsed quite flat and opened again some distance before cracking; but the annulus from the punched hole was so brittle that it cracked *on attempting to collapse it.* When, however, the latter was annealed, it became perfectly ductile; it could then be rolled out flat, and, still further, back upon itself, before cracking. This shows that the action of the punch merely hardens the steel, and does not, as was sometimes thought, produce minute radial cracks, for, of course, these would not be corrected by annealing. The reason why the brittle annulus of steel existing around each punched hole should reduce the tensile strength of a plate or test piece is explained by the fact that, while the ductile material yields readily and stretches to a stress, the brittle material does not; it therefore takes the bulk of the stress, and, being soon overpowered, cracks, when, of course, a fracture being started, complete rupture immediately ensues.

Experiments indicate that **when plates are riveted together, much of the loss of strength** caused by the punch **disappears.** This may be due to an annealing effect produced by the insertion and hammering up of the hot rivet, or to the bending or deformation of the plates when the joint is pulled asunder, which, having the effect of cold working, annuls to some extent the similar but local effect of the punch. Mr. Wildish found that, whereas in a $\frac{1}{2}$-inch plate the damage caused by punching $\frac{7}{8}$-inch holes lowered the strength from $28\frac{1}{2}$ tons to 22 tons, the strength of a similar plate, when riveted, rose to nearly 25 tons, *i.e.* a loss of 12 per cent. in place of 23 per cent. In thinner plates, which, as already seen, are not so prejudicially affected by the punch, the beneficial action of the riveting may make the final loss of strength quite inconsiderable.

In the **early days of steel** the injury which plates and bars suffered from the punch was a subject of much thought, for, owing to the variable and inferior qualities of the steel, the loss of strength was often exceedingly large (sometimes 50 per cent.); and although iron plates were known to suffer, the damage in their case was small, and, being fairly constant, could be neglected. With improvements in the manufacture of steel, however, the effect of the punch became less serious; nevertheless, it was sufficiently marked to raise the question whether or not pains should be taken to correct it, *i.e.* whether it was advisable and desirable to **anneal every structural part** of the hull in which holes were punched, or to **enlarge the holes by rimering.** As a means of ensuring perfect efficiency in the material, either plan would doubtless be commendable, but, on the other hand, various practical considerations exist which render both inexpedient.

In the case of **boilers**, the highest efficiency in material and workmanship is essential, and, accordingly, the **rivet holes** are usually **drilled**, or, if punched, the plates are annealed. But a boiler has widely different duties from the hull of a ship; it is designed to withstand a certain proof test, and a working pressure of fixed magnitude; and, to ensure perfect safety under these conditions, the highest structural efficiency is essential. In the **structure of a ship** there is no fixed maximum stress; severe tensile stresses may sometimes be experienced, but they are confined to such parts as the sheer strake. As regards the greater portion of the structure, there is a large margin of strength against tensile stresses. In

[1] See his book, "*The use of steel for constructive purposes*," published 1875.

the case of iron ships it was not found necessary or expedient to eliminate the damaging effect of the punch, and although thick steel plates may suffer perhaps twice as much as iron ones, thinner may be little more affected. But, moreover, steel is some 50 per cent. stronger than iron, and although much of this superiority is discounted by the 20 per cent. reduction made in the scantlings, there still remains an excess of strength of some 20 per cent. It is evident, therefore, that the adoption of costly refinements in the building procedure, such as rimering all punched holes or annealing all plates, is not called for.

But although, in the structure generally, it is not found expedient or necessary to take special measures towards remedying the damage done by the punch, this is not the case in important parts subject to severe tensile stress. In the case, for instance, of the sheer strake, upper-deck stringer, and garboard strakes, when the plates exceed a thickness of $\frac{1}{2}$ inch (in which case the injurious effect of the punch may be considerable), Lloyd's rules state that all holes are to be punched a size small and then be rimered or countersunk to the required diameter, or else the plates are to be annealed; and, further, that all buttstraps exceeding a thickness of $\frac{1}{2}$ inch are to be similarly treated.[1] It should be observed that more than half of the holes in the shell plating are countersunk, which operation removes most of the damaged material; and although in the others the damaged material remains, its prejudicial effect is discounted in some measure by the greater sectional area left between the holes. The holes in the buttstraps are not countersunk, as are those of the plates they connect; and so, in thick ones, connecting important parts liable to intense stress, it is well that the damaging effect of the punch should be corrected by annealing, especially as in these small parts this is a simple matter. When corrective measures are adopted in the case of the sheer strake, etc., instead of annealing the plates (which is tedious and is apt to cause shrinkage or shortening of the plate), the holes are punched small, the cylindrical ones being subsequently rimered and the others countersunk to size. The rimering may be done by machine, before the plates are put in place, but it is better to do it after they are screwed together, for then, besides removing the damaged steel, it secures the very desirable condition of perfectly fair holes and sound riveting.

Art. 287. There are **two features of weakness in a joint**: (1) the tendency of the rivets to shear, and (2) of the plates to break across at a line rendered weak by rivet holes. The first may be entirely provided against by simply increasing the number of rivets. The second cannot be altogether eliminated, for, of course, the rows of rivet holes must always constitute lines of weakness; it may be modified in almost any degree, however, by a suitable disposition of the rivets. In one case, for instance, the rivet holes in a row might be so close together as to cut away, say, 50 per cent. of the plate, reducing its effective breadth and strength by this amount, while in another, if twice as far apart (a corresponding increase being made in the number of rows), the loss would only be half as great, or 25 per cent. The rivet pitch might be increased indefinitely, until there remained only one rivet in each cross "row." The strength obtained would then be the greatest possible, namely, that of the intact plate reduced in breadth by one rivet hole. If the plate were, say, 10 inches wide (Fig. 1, Plate 49), and the rivets 1 inch in diameter, the "*efficiency*" of the joint would be 90 per cent.; if 20 inches wide, 95 per cent. In the joint shown in Fig. 1 the theoretical efficiency is 90 per cent.; it can evidently only fracture in one way, by the plate breaking across at either

[1] This rule is not now strictly enforced.

of the terminal rivets (Fig. 2); the rivets would not shear, for they are sufficiently numerous to give a combined shearing strength greater than the tensile strength of the intact plate (Fig. 4). The plate could not break across at any other line than A, for if, say, at B (Fig. 3), while the same sectional area of plate would have to be broken, there would be, in addition, a terminal rivet to shear; if it broke at the third rivet, two terminal rivets would have to be shown. The strengths of the joint by these different modes of fracture are given in the sketches.

In practice a joint would not be designed as in Fig. 1, Plate 49, but the well-known **diamond type of joint** (Figs. 5 to 19) may be equally efficient. That shown in Fig. 5 has an efficiency of 94 per cent., for it may be readily shown that the weakest mode of fracture is, as before, that across line A (Fig. 7), where there is only one rivet hole. The rivets would not shear (as in Fig. 11), for they are sufficiently numerous to give ample shearing strength. Fracture of the plate could not occur at any other line than A, for if at B (Fig. 8), while there would be a smaller breadth of plate—by the diameter of one rivet hole—to sever, there would be, as a deterrent, the terminal rivet to shear; and as the strength of this rivet is greater than that of the strip of plating cut away by the extra rivet hole (in line B), a greater force would be required to break the joint (the strength of a $\frac{3}{4}$-inch steel rivet is about 11 tons, while that of the strip of $\frac{7}{20}$-inch plate cut away by the rivet hole is only $8\frac{1}{2}$ tons). The sketches show the various modes of fracture and the strength of the joint by each one. The strength of the plate is taken as thirty tons per square inch, and the shearing strength of a $\frac{3}{4}$-inch steel rivet as 11·2 tons. When thick plates are connected in this way, double straps are employed (Fig. 12), so that the rivets may be in double shear; for in thick plates the diameter of the rivets is comparatively small, and so, if in single shear, they might be weaker than the strip of plating punched away by the hole, and, consequently, the weakest line of fracture would not be that through the single end rivet; and, further, as fewer rivets are required with double straps, they may be more compactly disposed. A double-strapped joint of diamond type is shown in Figs. 12 to 19; also the various modes of fracture and the strength by each one. The combined thickness of double straps must, of course, be greater than that of the plate, otherwise they would break under a small stress, through the highly perforated central row of holes (Fig. 19). The diamond-shaped joint has little application in shipbuilding, for, as every plate is necessarily weakened by a cross row of frame or beam rivet holes, it would be useless to endeavour to secure greater strength at intermediate places. A diamond formation is sometimes adopted, however, in bulkhead liners (Art. 213), which may be regarded as straps crossing a weak line of closely spaced shell rivets (see Fig. 14, Plate 21).

The joint shown in Fig. 1, Plate 49, is defective, practically, in that the two plates are insufficiently bound together, for moisture, having free access, would, in course of time, result in such an accumulation of rust that the two plates would be burst asunder (Art. 466). If only for this reason, all parts united by riveting must be thoroughly bound together, so as to hold the surfaces in close contact throughout. But the joint is also defective as regards its capabilities in resisting stress, for the marginal portions of the plates, remote from the rivets, would not contribute the same intense resistance as the central part; the latter, therefore, being unduly strained, would fail at an early period, and, of course, a crack once started would run across. And, further, owing to the great length of the joint, the rivets would not all suffer the same stress; they would if the plates were perfectly inextensible, but as steel has a certain amount of

elasticity, the end ones would suffer more than the others; they would, therefore, be the first to strain and become loose, the others being affected consecutively.[1]

The **unequal stress suffered by the rivets in a long joint,** due to elasticity of the steel, may be illustrated by a strip of rubber; if the end is fixed, say, by a couple of nails to a board, then, of course, when the rubber is stretched only the nail remote from the end will suffer stress and give useful resistance. The stretch of a steel plate within the elastic limit is so small as not to affect appreciably the efficiency of ordinary end joints; in the case of long joints, however, such as the landing edges of the shell plating, it is common to find that the terminal rivets, near some point of weakness, have become loose, while the others beyond, being less strained, are unaffected. A more important matter is the elastic "**give**" **or yield of the rivets** themselves under shearing stress, compared with which the stretch of a plate is inconsiderable. For instance, when subjected to a stress of $2\frac{1}{4}$ tons per square inch, while a rivet would yield about $\frac{1}{100}$ inch, a plate, in a length of 3 inches (the distance between two rivets), would only stretch about $\frac{\cdot 045}{100}$ inch, or 4·5 per cent. of the yield of the rivet.[2]

The principle of the diamond joint is very generally applied in the case of **strapped joints,** in which the **outer rows of rivets** may be spaced from 50 to 100 per cent. **further apart** than the others (see Figs. 22 and 25, Plate 49). In the joint shown in Figs. 22 to 24 the outer rows of rivets are 50 per cent. further apart than the others, and as fracture of either plate can only occur through one of these (this, as shown in the sketches, being the weakest mode of fracture), the lesser perforation results in a greater ultimate strength. As a wide spacing reduces the total number of rivets, it can only be adopted in treble or quadruple-riveted joints; even in treble-riveted joints a double pitch cannot always be advantageously employed, for, as the rivets in thick plates are comparatively small and weak, the omission of half of those in the outer rows, if it did not diminish too much the combined shearing strength, might too much reduce the power of those in the outer rows to resist the distortion shown in Fig. 6, Plate 48. The former defect is shown in Figs. 25 to 27, Plate 49, where it will be observed that the weakest mode of fracture is not in the line of the outer row (of widely spaced rivets), but in the line of the second, or by shearing all the rivets. In practice, therefore, in the case of plates thicker than about $\frac{1}{2}$ inch, only one-third of the rivets in the outer rows is omitted (Fig. 22), which places them one and a half times, in place of twice, as far apart. When great strength is required, double buttstraps are employed, for, as the rivets are then in double shear, they are virtually of large size; and as in this type of joint there is no distortion under stress, a wide spacing in the outer rows is not prejudicial. In lapped joints a close spacing is usually maintained in all rows, for although, as regards ultimate tensile strength, a wide spacing in the outer rows might be advantageous, it would result in greater distortion under stress, *i.e.* the edges of the plates would too readily open (as shown in Fig. 3, Plate 48), reducing the efficiency of the joint and destroying the caulking. It may be noticed here that the rules of the British Corporation permit of a 50 per cent. greater pitch in the outer rows of treble and quadruple-riveted end joints, whether lapped or strapped (Figs. 10 and 11, Plate 50), but the

[1] An interesting study of this principle, as applied to different kinds of joints, will be found in Mr. Milton's paper, "*Some notes on the strength of riveted joints*," *Trans. Institution of Naval Architects*, 1885.

[2] Kennedy, *Trans. Institution of Naval Architects*, 1885, p. 212.

pitch of the inner rivet rows is only 3 diameters in place of the $3\frac{1}{2}$ diameters required by Lloyd's rules.

Art. 288. The **end joints of the shell** are not designed in a manner to secure the highest ultimate strength, for in practice it is found advantageous to forego some theoretical efficiency in favour of large rivet strength. In the treble-riveted lap joints generally adopted for the shell (Fig. 8, Plate 50), the strength of the rivets, when of steel, may be more than 50 per cent. greater than that of the plate between them; with iron rivets, however, whose strength may be 20 or 30 per cent. less than that of steel rivets, the discrepancy is much smaller. This **excess of rivet strength** is found useful in checking straining tendencies in the joints through yielding of the rivets. When a joint is tested by tensile stress, long before it actually breaks, the rivets begin to yield and allow the parts to slip; and although, if tested to destruction, the rivets might prove stronger than the plate, still, a joint which had strained in this way would, for practical purposes, be reckoned as having failed. It should be observed that in testing an experimental joint, the conditions are very different from those which prevail in the structure of a ship; the joints in the latter may be much more severely tried, for the stress is not so uniformly applied as to subject each rivet to the same pull, nor does it act only in one direction, for one moment it is a pull, and the next a push; and, moreover, other stresses may occur simultaneously, vertical and lateral as well as longitudinal. The necessity for large rivet strength is shown by the circumstance that, while the rivets often strain and become loose, the plates between them rarely fracture. In many cases, for instance, the sheer-strake joints have strained so markedly that the intense local stress imposed on the intact plate below has caused it to fracture; and in other cases the straining of a sheer-strake joint has communicated with adjacent joints or points of weakness in the continuous strake, by loosening the intervening landing rivets. Such straining is, of course, due to insufficiency in the holding or clamping power of the rivets, and it is evident that, to prevent it, the faying surfaces of the joints must be bound together by numerous rivets, often largely in excess of what their ultimate strength in relation to that of the plate might indicate as proper.[1]

Art. 289. There is another important matter which emphasizes the need for ample rivet power, namely, the securing of large **frictional resistance in the joint.** When a joint is pulled asunder its resistance presents two phases: it offers at first a frictional resistance, during which there is absolutely no straining or relative movement of the parts; when this is overcome, which happens under a comparatively small stress, the rivets begin to yield and allow the parts to strain or slide over one another. The intensity of the frictional force depends on how tightly the rivets bind the two plates together, and on the roughness of the faying surfaces. When tightly bound, the minute roughnesses of the surfaces become interlocked, so that, on attempting to pull the one plate over the other, they give, for a time, a perfectly unyielding frictional resistance; during this phase the rivets are not strained, the joint, in fact, behaves like a solid plate.

Various experiments have been made to ascertain the magnitude of the frictional resistance of riveted joints, *i.e.* the stress at which relative slipping movement becomes perceptible. In the case of butted joints, they were made by riveting a narrow test plate, having oval holes, between two others (Fig. 8, Plate 48), and pulling on it until it slipped; and in lap joints, by making oval holes in one plate and clenching the rivets on washers (see

[1] An interesting paper on this subject will be found in Mr. Henry West's contribution to the *Trans. Institution of Naval Architects*, 1884.

Fig. 9). Mr. Wildish found[1] that the frictional resistance with 1-inch rivets, having snap heads and points, was equal to 6·4 tons per rivet; and with $\frac{3}{4}$-inch rivets, 4·72 tons; and when the points and heads were countersunk, 9·04 tons for 1-inch rivets, and 4·95 tons for $\frac{3}{4}$-inch rivets. These results are higher than those obtained by other investigators. Mr. Kennedy found that an ordinary single-riveted joint began to slip visibly when the stress reached 23·5 per cent. of the breaking strength, but, when hydraulic riveted, at 34 to 57 per cent.; that is to say, a joint riveted by hydraulic pressure was found to have about twice the frictional resistance of one riveted by hand. He also found that the frictional resistance was much the same whether a joint had single or double straps; why this is so is not clear, for with two straps the double surface should give double the frictional resistance; it is probably due to the fact that double straps, when under stress, tend to fall away from the plates. It should be observed that the *ultimate* strength of a joint is not affected by the magnitude of its frictional resistance, for this is overcome at an early period; and, accordingly, although a hydraulic-riveted joint has a higher frictional resistance than one riveted by hand, there may be no difference in the *breaking* strengths.

In the riveted joints of a ship, as indeed of all riveted structures, it is a very important matter to secure in such ample measure this valuable frictional resistance, that, under working conditions, it may not be exceeded; for then, in the absence of incipient straining, the rivets can suffer little or no stress. It may be obtained in any required degree by simply multiplying the rivets, for whether the faying surfaces be large or small, two rivets produce twice the frictional pressure that one does. The roughness of the faying surfaces is not very amenable to treatment, but it is evident that no foreign matter, such as would prevent close and uniform contact, should be allowed to remain between the surfaces, borings from drilled or rimered holes, for instance, and rust scale should be carefully removed before the parts are riveted together. It should be remarked that the thin skin of hard scale which forms between the surfaces of old joints is advantageous, for while, by acting like a cement, it makes the joint perfectly watertight, it also greatly increases the solidity and frictional resistance. This fact explains very well how it is that new vessels, in which the various joints have not had time to "rust up," are so much more liable to strain in their riveting than old ones, the design and trade in each case being the same. In most of the joints of a ship, the stresses experienced under ordinary working conditions do not exceed their frictional resistance; in large vessels, however, those suffered by parts such as the sheer strake, especially at the ends of deck erections, are often in excess.

Art. 290. As regards the **diameters and disposition of the rivets** in the various joints, there are several matters to consider. It may be stated generally that **largeness** in the rivets is **advantageous**; for, as their sectional area or strength increases as the square of their diameter, an increase in their size permits of a great reduction in their number; a 1-inch rivet, for instance, is equivalent, as regards shearing strength, to four $\frac{1}{2}$-inch ones. In practice, however, there are various matters which limit their diameter; thus, in thin plates, say $\frac{1}{4}$ inch thick, it is evident that 1-inch rivets would be quite disproportionately large (Fig. 12, Plate 48), for the individual strength of each one would be greatly in excess of any shearing force which the plates could bring to bear upon it. Long before the rivet was seriously strained, the hole in a plate so thin would stretch oval or tear, and the excessive *bearing pressure* (*i.e.* the pressure on the

[1] *Trans. Institution of Naval Architects*, 1885.

edge of the plate in contact with one side of the rivet) might cause the plate to bulge or curl up; or if the rivet had a countersunk point, it might pull through the hole, like a stud through leather. If three $\frac{5}{8}$-inch rivets were substituted for the one 1-inch one, their combined shearing strength would be much the same, but as the sum of their diameters would be about twice as great, the bearing pressure would be reduced by half; the holes, therefore, would not stretch oval, even though the rivets were strained to the shearing point. In experiments with riveted joints, it is found that, although the bearing pressure of the rivet on the edge of the plate in the hole may be exceedingly large, it has little compressive effect on the material of the plate. A chain cable affords a familiar instance of excessive pressure unaccompanied by deformation, for the links, while taking contact at mere points, may bear upon each other with a force of many tons—120 tons in the case of a $2\frac{5}{8}$-inch cable under proof test.

Disproportionately large rivets are objectionable from another point of view. In the case of watertight joints, for instance, the rivets must be sufficiently near the caulking edge to prevent the plates from separating under the lifting action of the caulking tool; experience shows that this distance should not much exceed twice the thickness of the plate, and if, in conforming with this limitation, 1-inch rivets were placed within half an inch of the edge of a $\frac{1}{4}$-inch plate (Fig. 12, Plate 48), it is evident that, when subjected to severe tensile stress, the resistance of the portion of the plate which lies between the rivet and the edge of the plate, to tearing or displacement, would be quite out of proportion to the large shearing strength of the rivet. But, further, for each thickness of plate there is a maximum distance between the rivets beyond which the faying surfaces would be insufficiently bound together. It is found, for instance, that to secure watertightness the distance between the rivets in thin plates should not exceed about eight times the thickness of the plate, and if, to comply with this requirement, 1-inch rivets, uniting $\frac{1}{4}$-inch plates, were placed 2 inches apart (3 inches centre to centre), it is evident that not only would the sectional area of the plate be seriously reduced—by 33 per cent.—by the perforation, but there would be a useless excess of rivet strength, for the sectional area of the 2-inch strip of plate would only be about half the sectional area of each rivet.

Theoretical investigation, experiments with riveted joints, and practical experience all indicate that, for thin plates, the rivets are not too large when their diameter is about *twice the thickness* of the plate; when placed a distance of one diameter clear of the edge, the shearing resistance of the plate immediately in front is then in excess of that of the rivet, and the edge is sufficiently held against the separating action of the caulking tool. But, of course, rivets so large as twice the thickness of the plate can only be employed in thin plates, for, in thick, they would be absurdly large. Their size here is limited by the practicability of efficiently "*closing*" them, *i.e.* of staving them up and clinching their points with hand hammers. Excepting the long rivets used in keels, sternposts, etc. (which may be $1\frac{1}{4}$ inch diameter), 1 inch is the largest size used in ordinary shipbuilding; but even these are too large for convenient manipulation; to close them efficiently, so as to ensure perfect soundness, extra large hammers must be used, and special care observed. Except in very large vessels, few of the rivets exceed $\frac{7}{8}$ inch, and this is the largest that can be conveniently and expeditiously manipulated with ordinary hand hammers and the assurance of sound work.

TABLE SHOWING THE DIAMETERS OF RIVETS AND BREADTHS OF BUTTSTRAPS AND OVERLAPPED JOINTS REQUIRED BY LLOYD'S RULES.

	Inches. $\frac{5}{20}$	Inches. $\frac{6}{20}$	Inches. $\frac{7}{20}$	Inches. $\frac{8}{20}$	Inches. $\frac{9}{20}$	Inches. $\frac{9\&10}{20}$	Inches. $\frac{10}{20}$	Inches. $\frac{11}{10}$	Inches. $\frac{12}{20}$	Inches. $\frac{13}{20}$	Inches. $\frac{14}{20}$	Inches. $\frac{15}{20}$	Inches. $\frac{16}{20}$	Inches. $\frac{17}{20}$	Inches. $\frac{18}{20}$	Inches. $\frac{19}{20}$	Inches. $\frac{20}{20}$
Thickness of Plates																	
Diameter of Rivets	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	1	1	1	1	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{8}$
Breadth of Treble-riveted Straps ...	—	—	—	$14\frac{1}{4}$	$14\frac{1}{4}$	$14\frac{1}{4}$	$16\frac{3}{4}$	$16\frac{3}{4}$	$16\frac{3}{4}$	$16\frac{3}{4}$	19	19	19	19	$21\frac{1}{2}$	$21\frac{1}{2}$	$21\frac{1}{2}$
„ „ Double-riveted „ ...	8	8	$9\frac{3}{4}$	$9\frac{3}{4}$	$9\frac{3}{4}$	$9\frac{3}{4}$	$11\frac{1}{4}$	$11\frac{1}{4}$	$11\frac{1}{4}$	$11\frac{1}{4}$	—	—	—	—	—	—	—
„ „ Quadruple-riveted Butt Laps	—	—	—	—	—	—	12	12	12	12	14	14	14	14	16	16	16
„ „ Treble-riveted Butt Laps	—	—	—	$7\frac{1}{2}$	$7\frac{1}{2}$	$7\frac{1}{2}$	9	9	9	9	$10\frac{1}{2}$	$10\frac{1}{2}$	$10\frac{1}{2}$	$10\frac{1}{2}$	12	12	12
„ „ Double-riveted „ „	$4\frac{1}{4}$	$4\frac{1}{4}$	5	5	5	5	6	6	6	6	—	—	—	—	—	—	—
„ „ Treble-riveted Edge Laps	—	—	—	—	—	—	—	—	—	$7\frac{1}{2}$	$8\frac{1}{2}$	$8\frac{1}{2}$	$8\frac{1}{2}$	$8\frac{1}{2}$	$9\frac{1}{2}$	$9\frac{1}{2}$	$9\frac{1}{2}$
„ „ Double-riveted „ „	$3\frac{3}{4}$	$3\frac{3}{4}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$5\frac{1}{4}$	$5\frac{1}{4}$	$5\frac{1}{4}$	$5\frac{1}{4}$	6	6	6	6	$6\frac{3}{4}$	$6\frac{3}{4}$	$6\frac{3}{4}$
„ „ Single-riveted „ „	$2\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{1}{2}$	3	3	3	3	—	—	—	—	—	—	—

Art. 291. The foregoing table exhibits the **requirements of Lloyd's rules as to riveting.** It will be observed that the smallest rivet is $\frac{5}{8}$ inch; this is rather larger than twice the thickness of the $\frac{1}{4}$-inch plating for which it is applicable, but it is found, by experience and by the ordinary conditions of practice, to give good results; $\frac{1}{2}$-inch rivets would also be quite suitable, but, being only two-thirds as strong, a greater number would be required and the cost of workmanship would be increased. On comparing a 1-inch rivet in a $\frac{17}{20}$-inch plate with a $\frac{5}{8}$-inch one in a $\frac{5}{20}$-inch plate, it appears disproportionately small; but, as already seen, this is the largest that can be conveniently hammered up, and, moreover, unlike excessive size (the prejudicial effects of which have just been noticed), relative smallness is not necessarily accompanied by lack of efficiency, for any required shearing strength in the rivets of a joint may be obtained by simply increasing their number. Thus, while in thin plates single riveting may suffice, in thicker, double is employed, or, if necessary, treble or quadruple, or the joint may be connected by double straps, which at once increases the capabilities of the rivets by about 75 per cent.

It is seldom if ever necessary to use a rivet of smaller diameter than the thickness of the plate; if much smaller the holes would have to be drilled; they could not be punched, for the pressure on the tool would be greater than ordinary tool steel could withstand. A good $\frac{3}{4}$-inch punch may perforate a 1-inch plate, but it would not endure very long. The **strength of a punch,** being that of a short cylinder under compression, varies as its sectional area, *i.e.* as the *square* of its diameter; but the work it does, or the pressure it suffers in punching a hole in any particular plate, varies as its circumference (the length of the sheared edge of the hole), which, of course, varies as its diameter; accordingly, if the diameter of a punch were, say, reduced by 50 per cent., then, while the work required of it in punching a hole would be half as great, it would only be one-quarter as strong, and would, therefore, suffer twice as much compressive stress per square inch.

Excepting the few **rivets** used in keels, sternposts, etc., which may be as large as $1\frac{1}{4}$ inch diameter, there are only **five sizes employed** in ordinary ship work: $\frac{5}{8}$, $\frac{3}{4}$, $\frac{7}{8}$, 1 inch, and $1\frac{1}{8}$ inch ($1\frac{1}{8}$-inch rivets, being only required for plates $\frac{18}{20}$ inch thick, are little used). For light scantlinged yachts, etc., $\frac{1}{2}$-inch and $\frac{3}{8}$-inch rivets are employed, but when so small as $\frac{3}{8}$ they are usually clinched cold. As shown in the table on the opposite page, each size of rivet serves for several thicknesses of plate, and, with a view to securing greater theoretical uniformity, it has been attempted to introduce intermediate sizes, $\frac{11}{16}$, $\frac{13}{16}$, etc.; but this course did not meet with favour, because, while securing no practical benefit as regards the efficiency of the riveting, it caused inconvenience and complications, for it involved numerous punches and dies, and mistakes occurred in their use. Simplicity and convenience in the practical work of the shipyard are often found more important than theoretical perfection.[1]

The **diameter of the rivets is regulated by the thickest** of the plates or bars through which they pass. This is evidently proper, for it may be the thickest part which is pulled into position by the rivets. An exception may be made, however, where very thick plates are connected to very thin, as, for instance, the thin bulwark to the thick sheer strake;

[1] In the s.s. *Great Eastern* the principle of simplification was particularly studied; there was only one size of rivet, $\frac{7}{8}$-inch, and one pitch, 3-inch; and, excepting some of the end joints of the shell, all joints were single riveted. There were only two thicknesses of plates, $\frac{3}{4}$ inch for the shell and inner bottom, and $\frac{1}{2}$ inch for the remainder; and only one size of angle bar, 4 by 4 by $\frac{5}{8}$ inch (see Scott Russell's "*Naval Architecture*," page 394).

and in the case of small-flanged angle bars, where a large rivet would cut away too much of the material; in a 3-inch flange, for instance, the rivets should not exceed $\frac{7}{8}$ inch. The diameter of the rivets is usually the same whether they pass through two or more thicknesses. To pull together three parts causes much the same stress on the rivets as to pull two together, for it is only the two outer ones that are pulled against the central. When there are more than three thicknesses, however, the rivets may suffer abnormal stress, and so, in important parts, they should be increased either in size or number.

The **long rivets** connecting the shell to the keel, stem, or sternpost are always of **extra large size**: Lloyd's rules require them to be $\frac{1}{4}$ inch larger than is otherwise appropriate for the plating. In side-bar keels there are five thicknesses to pull together, and as in doing so the rivets may suffer severe tensile stress (tending to pull their heads off), they should evidently be specially strong. In bar keels, stern-frames, etc., as there are only two plates to pull together, the rivets may suffer no unusual stress; nevertheless, they should be extra strong, for their great length reduces the rigidity of their binding effect. When subject to tensile stress, the stretch of a rivet or rod (within the elastic limit) varies as its length, and, accordingly, although a long rivet may exert the same binding or clamping effect as a short one, it is more yielding, *i.e.* under sudden stress it may stretch and let the parts slip. But, apart from their duty in binding the plating, the rivets in a bar keel are particularly exposed to intense shearing and other stresses due to grounding; after such a casualty it is not uncommon to find many of the keel rivets loose or broken, a circumstance which, of course, is well provided against by making them large and strong. The pitch of keel rivets is usually 5 diameters; with thin plates this is rather large for caulking purposes. The riveting of the rudder is described in Arts. 266, 267, and 270, and further remarks on the riveting of keels will be found in Art. 75.

Art. 292. Rivet holes must be punched rather **larger than the rivets**, so that the latter may be inserted when swollen by heat; the finished diameter of a rivet, when staved up, is, therefore, rather greater than it was originally. In specifying the size of rivets, it is the original or manufactured diameter that is referred to, and this fact should be borne in mind when estimating the shearing strength of the rivets in a joint. The allowance made for the swelling of the rivets should evidently vary with their diameter; in practice, however, very little precision is observed in this matter, the allowance generally made varying roughly from $\frac{1}{16}$ inch for a $\frac{5}{8}$ rivet to $\frac{3}{32}$ inch for a $\frac{7}{8}$ one. In many cases the allowance for small rivets is more than sufficient (the men prefer to make large holes, for it ensures the easy insertion of the rivets, even though the holes may be unfair), but as these are usually short, they may be readily staved up so as to fill the holes. In the case of keel and stern-frame rivets, which are not easily staved up, the holes should be no larger than is necessary, *i.e.* the hot rivets should fit tightly in the holes (Art. 315).

Art. 293. The **pitch of the rivets** (*i.e.* the distance apart, centre to centre, in each row) is an important matter, for it is this which sets a limit to the efficiency of the joint. The pitch specified in Lloyd's rules for the end joints of steel shell plating is $3\frac{1}{2}$ diameters, and for those of iron plating 4 diameters. When steel superseded iron, while its greater strength permitted of thinner plates, it did not allow of any reduction in the size or number of the rivets, for, of course, the superior strength of steel plating does not extend to the riveting of its joints. But even a strict identity in the riveting of steel and iron vessels would only be correct if the thin steel

plates were of precisely the same strength as the thicker iron ones, and if the rivets were equally efficient in both materials. This is not the case, however, for the 20 per cent. reduction made in the thickness of steel plating still leaves it about 20 per cent. stronger than iron plating, and when iron rivets are employed to connect the steel plates (as is still common) their shearing strength is lowered by some 14 per cent.; that is to say, while the plating of a steel ship is stronger, the riveting, if no more extensive than in an iron one, would be weaker. Accordingly, with the introduction of steel, this discrepancy was adjusted by the simple plan of reducing the rivet pitch of the end joints from 4 to $3\frac{1}{2}$ diameters; for, by giving some 14 per cent. more rivets, it provided for their smaller shearing strength, and the 14 per cent. greater perforation of the plates was admissible in view of the steel, though thinner, still possessing about 20 per cent. surplus strength. A reduction in the rivet pitch, moreover, carries with it the advantage of diminishing somewhat the injurious effect of the punch (Art. 286).

Art. 294. In the structure of a ship the joints of the numerous parts —differently situated and serving different purposes—have very different responsibilities, and, according to their importance, they are single, double, or treble-riveted. **An ordinary single-riveted joint is not an efficient one,** for the combined strength of the rivets is much less than that of the plate between them. Of course, by placing the rivets sufficiently close together, the discrepancy might be corrected, for while the plate would become weaker owing to the greater perforation, the rivets would become stronger owing to their greater number. In ship work, however, a closer pitch than $3\frac{1}{2}$ diameters is seldom adopted;[1] when greater strength is required it is secured in a more efficient manner by double or treble riveting. The inefficiency of a single-riveted joint is much greater in thick than in thin plates, for in the former the rivets are relatively small. If the diameter of the rivets were proportionate to the thickness of the plates, and the pitch, in diameters, were invariable, then, whether the plates were thick or thin, the sectional area or strength of the rivets would bear a constant ratio to that of the plate between them. But in practice such similarity of conditions does not prevail, for while the rivets used in $\frac{5}{20}$-inch plates are $\frac{5}{8}$ inch, those in $\frac{9}{20}$-inch plates are only $\frac{3}{4}$ inch; if proportionate, the latter would be $1\frac{1}{8}$ inch in diameter. In a single-riveted joint of $\frac{1}{4}$-inch plating, having countersunk steel rivets pitched at $3\frac{1}{2}$ diameters, the strength of the plate between the holes is about 30 per cent. in excess of that of the rivets, and in $\frac{9}{20}$-inch plates about 90 per cent. This assumes the rivets to have a shearing strength of 22 tons per square inch, and the plates a tensile strength of 30 tons; in the case of iron rivets, whose shearing strength is only about $16\frac{1}{2}$ tons, the discrepancy is much greater. In practice, therefore, as plates increase in thickness, single riveting gives place to double, and double to treble. It should be observed, however, that in joints having no great responsibility, such as those which serve merely as an edge or watertight binding, single riveting, even with thick plates, may be sufficient.

The strength of an iron plate, per square inch, is much the same as that of an iron rivet, and, consequently, in the single-riveted joints of thin plates there may be little discrepancy in the strength of the plate and of the rivets; that is to say, if pulled asunder the plates would be no more likely to tear along the line of holes than the rivets would be to shear.

[1] The British Corporation specify a 3-diameter pitch for single-riveted end joints, as also for the central rows of treble and quadruple-riveted end joints (Figs. 10 and 11, Plate 50).

This is particularly the case in edge seams, for, owing to the well-developed fibre of iron plates, their cross tensile strength is considerably less than their longitudinal. It is on account of this that iron buttstraps must always be cut crosswise from the plate, so that the fibre may lie fore-and-aft, in the direction of the stress. In steel plates there is no fibre, and little, if any, difference in the mechanical qualities, whether tested longitudinally or crosswise.

Art. 295. In the riveting of watertight joints what is known as **watertight pitch** is a variable quantity; anything under 5 diameters is usually regarded as such, but whether rightly so or not depends on the thickness of the plates, the water pressure, and the kind of joint. In a lap joint it must be such that the plates, in the distance between a pair of rivets, may not be so flexible as to spring asunder under the separating action of the caulking tool, and subsequently when water under pressure enters between the faying surfaces. The more uniformly the plates are bound together, by closely spaced rivets, the more readily is the joint caulked and the more secure and permanent the watertightness. If the rivets were so close together as to have a perfectly continuous clamping effect, the contact of the faying surfaces would be so perfect that the joint would be watertight without caulking. If, on the other hand, they were wide apart, say 10 inches in a $\frac{1}{2}$-inch plate, the contact of the faying surfaces between each pair of rivets, distant 20 times the thickness of the plate, would, evidently, be quite imperfect; to caulk the edge, moreover, would be impossible, for while the staving effect of the tool might produce contact at one spot, the same effect at the next would disturb it. But although a pitch of 10 inches would be absurdly large for $\frac{1}{2}$-inch plating, it might be compatible with watertightness in 1-inch plating, if the caulking surfaces were brought thoroughly close by the riveting, and the caulking were carefully done, *i.e.* with such light, uniform blows that their staving tendency at one place did not injure the contact secured elsewhere; but the watertightness would not be substantial or permanent; if water under pressure entered between the faying surfaces, it would separate the plates sufficiently to pass through, bulging them in small arcs between the rivets, and, when subjected to the blows of wear and tear, the shocks would disturb the caulking.

The tendency of water under pressure to force the plates asunder between the rivets is proportional to the distance between the latter. The short piece of plate between two rivets may be regarded as a beam subject to a distributed load of fixed intensity per unit of length, so that twice the length, or rivet pitch, means twice the load or bulging tendency. If the load (or total water pressure acting between each pair of rivets) were invariable, then, as the flexibility of a beam varies as the cube of its length, and inversely as the cube of its thickness, the rivet pitch necessary to secure equality of stiffness in resisting water pressure would be proportional, simply, to the thickness of the plate. If, for instance, in a $\frac{1}{4}$-inch plate, a pitch of nine times the thickness, or $2\frac{1}{4}$ inches, were suitable for watertightness, then, in a 1-inch plate, a pitch of nine times the thickness, or 9 inches, would be equally suitable, the resistance offered to deflection being the same in either case. But as the water pressure acting between the rivets is proportional to the distance between them, it would be four times as great in the 1-inch plate, so that the tendency to deflect would also be four times greater; it is evident, therefore, that to secure equality the pitch in the case of the 1-inch plate must be reduced. The reduction, however, need only be comparatively small, for not only does it carry with it a corresponding diminution in the water pressure, but an increase in stiffness proportional, inversely, to the third power of the reduction in length. If the pitch be estimated on the above basis (*i.e.* so as to give,

in plates of different thickness, equal stiffness between the rivets, and assuming a pitch of nine times the thickness to be suitable for a $\frac{1}{4}$-inch plate) it will be found that the pitch, in rivet diameters, suitable for a $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$, and $\frac{3}{4}$-inch plate, having respectively $\frac{5}{8}$, $\frac{3}{4}$, $\frac{7}{8}$, and 1-inch rivets, will be approximately $3\frac{1}{2}$, 4, $4\frac{1}{4}$, and 5 diameters.

In ordinary ship work the rivet pitch generally adopted in watertight joints is 4 to $4\frac{1}{2}$ diameters; for although in thick plates this may be unnecessarily small, still, owing to the small size of the rivets compared with the thickness of the plate, the greater number is advantageous in securing ample rivet strength; and although, similarly, in the case of thin plates it may be disproportionately large, still, it is not unsuitable here either, for thin plates are not usually subject to the same intense water pressure as thick ones, and as the rivets are large in proportion to the thickness of the plate, they may, though few in number, be amply strong. The water pressures prevailing in a ship are, of course, comparatively small, a head of 34 feet—which represents 15 pounds per square inch—being rarely attained even in the largest vessels. In steam boilers the pressure may be 200 pounds per square inch, which represents a head of water of 450 feet; here, therefore, not only must the plates be thick, but the rivet pitch small. In ship work, while a pitch of 4 to $4\frac{1}{2}$ diameters is generally suitable, a closer pitch may be adopted in special cases, where, for instance, owing to inaccessibility, the caulking is difficult to perform, and where, at the same time, absolute watertightness is essential, as in watertight collar angles and connecting bars of ballast tanks or bulkheads, where the rivets pass through several thicknesses; here, thorough initial contact by means of closely pitched rivets is most desirable, for watertightness is then assured almost independently of the caulking. In the case of butted joints, not liable to intense water pressure, the rivet pitch, as regards watertightness, is less important than in lapped joints, for the caulking tool does not tend to lift or separate the plates. The rivets in the end joints of the shell plating (when treble or double riveted) are spaced $3\frac{1}{2}$ diameters apart, but this close pitch is for strength, not for watertightness. In the case of oil vessels, however, even so close a pitch as $3\frac{1}{2}$ diameters is too great for oil-tightness; in these vessels, therefore, a pitch of 3 diameters is usually adopted for oil-tight parts.

Art. 296. Lloyd's rules specify the rivet pitches required for the various parts of the hull. There are seven in all, namely, $3\frac{1}{2}$, 4, $4\frac{1}{2}$, 5, $5\frac{1}{2}$, 6, and 7 diameters.

A $3\frac{1}{2}$-diameter pitch is required for double or treble-riveted end joints of shell plating, of spar, upper, middle and shelter or awning-deck stringer plates, and of bridge-deck stringer plates where the length of the bridge exceeds one-third the vessel's length amidships (Art. 287).

A 4-diameter pitch is specified for all quadruple riveted joints, for the end joints of deck plating, lower-deck and hold stringer plates, the stringer plates of deck erections (other than bridge decks exceeding one-third the vessel's length), tie plates, floor plates, tank-margin plates and girders, for all the joints of tank-top plating, for the shell landings before and abaft the flat 'midship body if the frame spacing is 26 inches or greater, and for the shell landings on the flat part of the bottom for one-fifth the length at the fore end of vessels whose form is full at this part, or which have a tonnage coefficient of 0·78 or above.

A $4\frac{1}{2}$-diameter pitch is specified for the joints of bulkhead plating, for the fore-and-aft seams of deck plating, for gunwale bars and tank-margin shell angles, and for the shell landings before and abaft the flat 'midship body if the frame spacing is less than 26 inches.

A 5-diameter pitch is specified for the angles connecting vertical-plate to flat-plate keels, for the caulked shell angle of watertight bulkheads, for all the joints of masts and yards, for the rivets connecting deck plating to beams where the latter are on alternate frames and have only a single top flange, and for the rivets in bar keels, stems, stern-frames, and rudders.

A 5½-diameter pitch is specified for the rivets connecting the shell to the frames on the flat part of the bottom, for one-fifth the length at the fore end of vessels whose form is full at this part, or which have a tonnage coefficient of 0·78 or above.

A 6-diameter pitch is specified for the rivets connecting the shell to the frames in way of deep and peak tanks; and for *all* shell-to-frame rivets where the frame spacing is 26 inches and above.

A 7-diameter pitch is specified where a mere binding effect is required; for the rivets connecting the frames to the shell (with the above exceptions), reverse frames to tank-top plating and floors, hold-stringer and web-frame face angles, the different bars of side stringers, keelsons, and deck girders, and the bars of built beams to one another, deck plating to beams (excepting beams having a single top flange and which are spaced on alternate frames), bulkhead stiffeners, and all the angle bars of intercostal tank girders or longitudinals. Formerly 8 diameters was the usual pitch for all these parts, but it was found desirable to reduce it, to bind the parts more thoroughly together, and to avoid the prejudicial effect of corrosion mentioned in Art. 466.

The pitch of the rivets in the shell landings amidships, where the frame spacing, as measured on the shell, does not vary, is given in the table below. It should be observed that, owing to the constantly varying dimensions and form of the different parts of the hull, it is impossible to adhere to any precise pitch; those specified above are the maximum allowed by Lloyd's Register. In some cases smaller are adopted.

MINIMUM NUMBER OF RIVETS IN EDGES OF PLATING BETWEEN FRAMES *AMIDSHIPS*, EXCLUDING RIVETS IN FRAMES.

Spacing of Frames.	Number of Rivets in each row.				
	Diameter of Rivets.				
	⅝ inch.	¾ inch.	1 7/8 inch.	1 inch.	1⅛ inch.
20 inches.	7	5	—	—	—
21 „	7	6	5	—	—
22 „	—	6	5	—	—
23 „	—	6	5	5	—
24 „	—	7	6	5	—
25 „	—	—	6	5	—
26 „	—	—	7	6	5
27 „	—	—	7	6	5
28 „	—	—	7	6	6
29 „	—	—	8	7	6
30 „	—	—	8	7	6
31 „	—	—	—	7	6
32 „	—	—	—	8	7

Art. 297. The **end joints of the shell plating** are now **practically always lapped.** Formerly this practice was regarded with disfavour;

the butted joints then in vogue were invisible, and left the shell perfectly smooth; it was thought that lapped joints looked clumsy and cheap, and that, as protuberances, they would interfere with the vessel's movement, and be a source of damage in case of contact with external bodies. But with greater familiarity they are no longer thought unsightly—indeed butted joints are often more disagreeably noticeable, for although nominally invisible, they often declare themselves aggressively by an ugly streak of rust, or by an open crevice. Lapped joints are not found to be a source of damage through contact with other bodies; and any augmentation they cause in the vessel's resistance is inconsiderable, and is only occasionally thought worthy of consideration in light, high-speed steamers and yachts, where, for the sake of a perfectly flush surface, butted joints are still sometimes preferred.

A **lapped joint** has many practical **advantages over a butted one.** It is more easily and efficiently caulked, the work of fitting a strap and half its weight is avoided; there is only half as much riveting, and as the joint is only half as wide, there is always ample space for it between the frames. A buttstrap of an outside strake does not entirely cover the joint, and so to this extent a butted joint is less strong than a lapped one. The former must be fitted with special care, so that the ends of the plates may abut in actual contact throughout; in the bilge strakes, owing to their transverse curvature this condition is difficult to secure, and, consequently, the joints are usually more or less open. When an imperfectly butted joint is caulked, the plates are only brought together by the caulking tool on the surface (Fig. 6, Plate 54); or if the edges are too wide apart, strips of sheet iron are driven between as a preliminary to the caulking. This practice is very objectionable, for when corrosion sets in (intensified as it is by the presence of the foreign material) the butt soon becomes an open crevice; in old ships the butts of the bilge strakes are sometimes so corroded that the finger may be inserted between the ends of the plates (Fig. 13, Plate 48). The readiness of the butts at the bilge to corrode and become open crevices is sometimes taken as an indication of straining and weakness. That this behaviour, however, is not necessarily due to straining is proved by the fact that, in cases where two contiguous strakes are jointed, the one with butted and the other with lapped joints, while the former joints show the usual tendency to open, the latter are unaffected; if there were any actual straining it would not be confined to the joints of the one strake.

In a **butted joint** the lateral deformation which occurs under stress (Figs. 4 to 6, Plate 48) tends to open the caulking and assist corrosion, and repeated recaulking furthers the formation of a corroded crevice. At each dry docking, butts, when too much corroded to caulk, are usually filled with cement; and sometimes, when very open, the substantial remedy is adopted of covering them with external buttstraps. In a lapped joint the caulking is little affected by corrosion; if the joint should strain excessively, the caulking would, no doubt, be spoiled, but it may be recaulked as efficiently as before. The lateral straining of butted joints is checked by making the straps thicker than the plates. Lloyd's rules require treble-riveted shell straps to be from $\frac{1}{20}$ to $\frac{4}{20}$ inch thicker, according as the thickness of the plates varies from about $\frac{1}{4}$ to $\frac{3}{4}$ inch. At one time, instead of thickening the strap, it was sometimes preferred to fit two or three short stiffening bars across it, as shown in Fig. 15, Plate 50.

As noticed in Art. 287, a butted joint has the advantage of permitting a wide pitch in the outer rows of rivets, so that, by the smaller perforation, the strength of the plate may more nearly equal that prevailing at a

line of frame rivets. In a treble-riveted **lapped joint** this cannot well be done, for, to check the lateral deformation shown in Fig. 3, Plate 48, and avoid starting the caulking, the outer rows of rivets should have the full binding effect due to a close spacing. In the case, however, of quadruple-riveted lap joints, which, owing to their greater breadth, are subject to less deformation under stress, the pitch of the outer rows is sometimes increased to 5 diameters, as shown in Fig. 17, Plate 50; otherwise the pitch of all the rivets is increased to 4 diameters, as shown in Fig. 9. To secure greater efficiency in lap joints, it has been proposed to fit a back strap, as shown in Fig. 12, Plate 59, which, while retaining a close spacing in the rivets next the caulking edge, admits of widely spaced terminal rows; but this arrangement has found little or no favour in shipbuilding. Butted joints have the further advantage that the rivets are only strained when the plates are subject to tensile stress, for, of course, the abutment of the ends of the plates offers a perfect resistance to compression. In the sheer strake, for instance, which may suffer alternately intense tensile and compressive stress, the rivets in a lapped joint are one moment strained in one direction and the next in the other (assuming the stress to exceed the frictional resistance of the joint). In a butted joint the straining tendency has a smaller range, and so must be less trying on the riveting; but, of course, this superiority can only be apparent under a stress excessive as regards the shearing strength of the rivets.

Art. 298. A **double-strapped joint** has several advantageous features; owing to the double shear of the rivets, fewer are required, and so the joint may be short; and as, owing to its symmetry, there is no distortion under stress, a wide pitch in the outer rows is always admissible. In practice, however, the pitch is limited on account of the caulking, for double straps are individually thin—little more than half the thickness of the plates connected—and as the rivets are of the large size appropriate to the latter, a spacing, say, of 7 diameters might have an insufficient binding effect on the caulking edge of the thin strap. In boiler work, where a high efficiency in the joints is required, this is sometimes overcome by forming the straps as shown in Fig. 20, Plate 50, where it will be observed that, while the transverse pitch of the outer rows is large, the curved caulking edge of the strap is well bound by closely pitched rivets. More usually, however, both straps are made the full thickness of the plates connected (plates $1\frac{1}{2}$ inch thick, for instance, are commonly connected by two treble-riveted straps, each $1\frac{1}{2}$ inch thick, the rivet being $1\frac{1}{2}$ inch diameter), so that their edges may be well caulked, even though the rivets are widely spaced; the usual pitch for the outer rows, in such cases, is about $6\frac{1}{2}$ diameters, and for the inner rows $3\frac{1}{4}$ diameters.

Double buttstraps may be double, treble, or quadruple riveted. When double riveted they form a substitute for a treble-riveted, single-strapped, or lapped joint. When employed for the sheer strake or deck stringer they are usually treble riveted, in which case they form a substitute for a quadruple-riveted overlap, or for a single strap having four or five rows of rivets, which, of course, would be too broad for an ordinary frame space. They are not often quadruple riveted, unless with a view to reducing the bearing pressure on the side of the rivet holes in the plate, the intensity of which is a disadvantage peculiar to double straps. The combined thickness of double straps is made greater than that of the plate by 20 to 25 per cent., and if, in one of the straps, the holes are countersunk, its thickness is further increased by $\frac{1}{20}$ or $\frac{2}{20}$ inch, to make good the sectional area removed by the countersink.

Art. 299. Lloyd's rules as regards the breadth of lap joints

and buttstraps are shown in Figs. 6, etc., Plate 50, and in the table, page 274. It is also specified that in overlapped end joints the distance between cross rows of rivets, centre to centre, shall be $3\frac{1}{2}$ diameters, in strapped joints 3 diameters, and in edge seams $2\frac{1}{2}$ diameters; and, further, that no rivet shall be nearer the edge of the plate than its own diameter—edge of plate to side of rivet. It will be found, on comparing the above requirements with the specified breadths of overlap or of straps, that there is a small margin of breadth. This may be usefully applied in slightly increasing the distance of the outer rows of rivets from the edges of the plate, a rather greater distance than the minimum of 1 diameter being advantageous as a provision against irregularities in punching the holes, and in allowing some spare material for chipping should it at any time be required to recaulk the joint, the latter operation being preceded by chipping the edge to remove the old caulk. In old vessels the edges of the shell plates are sometimes so eaten away by corrosion as to bring them close to the rivets, a circumstance necessitating new plates. The rows of rivets are spaced further apart in a lapped joint than in a strapped one, because, while there is always ample room between the frames for an overlap, there is not always sufficient for a treble-riveted strap, and, of course, width of overlap is advantageous in reducing the tendency of the joint to distort under fore-and-aft stress (Figs. 1 to 3, Plate 48). The breadth of the overlap of double-riveted end joints is rather greater than that of the landings, for the end joints are subject to fore-and-aft stress, with its distorting tendency. In some cases the breadth of overlap adopted is considerably greater than that specified in Lloyd's rules (Fig. 27, Plate 92), it being found convenient to so proportionate it that the vertical rows of rivets may fall in line with the ordinary holes in the landings. When this is not done an extra pair of rivets may be required in the landings, in way of each joint (Fig. 28). With double straps, as the rivets are in double sheer, they may bear with greater pressure on the edge of the plate in the holes, and so it is well, in their case, that the inner rows of rivets should be placed at rather a greater distance than 1 diameter from the ends of the plates.

Art. 300. Lloyd's rules require (in vessels over 16,000 plating numeral) all overlapped **end joints of shell plating** to be treble riveted, with three full rows of rivets; except in small vessels, where those for one-quarter the length at the bow and stern may be double riveted. In large vessels (over 28,000 plating numeral) whose length exceeds twelve times the depth, the joints amidships of the sheer strake and strake below, and those of the upper-deck stringer plate, must have treble-riveted double straps in place of the ordinary treble-riveted overlap connection; otherwise, quadruple-riveted overlap joints may be substituted. As noticed in Art. 118, when shell plates exceed a certain breadth the weakening effect of individual joints becomes more pronounced; in such cases, therefore, to secure greater efficiency they are quadruple instead of treble riveted, the pitch of the rivets being increased to 4 diameters instead of $3\frac{1}{2}$ (Fig. 9, Plate 50), in some cases the pitch of the inner rows is retained at $3\frac{1}{2}$, and that of the outer increased to 5 diameters (Fig. 17). As regards the now uncommon butted joints, Lloyd's rules are not so simple; as vessels increase in size, the requirements as to treble riveting are applied in a gradual way: first to the sheer strake, and to one, two, or three strakes at the bilge, then to the remaining outer strakes, and finally to all. And, according to the vessel's size, the treble riveting is required for half length, three-quarter length, or all fore-and-aft, the pitch of the outer rows of rivets and the thickness of the straps being also governed by the size of the vessel.

Art. 301. The **rivets** in the different rows may be placed opposite one another, in **chain** fashion, or they may be **zigzagged** (see Fig. 18, Plate 50). In the early days of iron shipbuilding the zigzag arrangement was common, for it was thought to be the stronger; later, however, it was ascertained by experiment that the strength of a joint is practically the same either way, and as chain riveting lends itself better to ship work, it is now exclusively adopted, and is required by the classification societies. Zigzag riveting is objectionable, in that the rivets of the landings do not fall symmetrically with the end joints, and are apt to foul the ends of the plates, the frames, or other cross bars (see Fig. 18). The only parts in which zigzag riveting is still sometimes adopted are the masts, keels, stems, and quadruple-riveted lapped joints. In the case of angle bars subject to longitudinal stress, it is evident that, to minimize the weakening effect of the rivet holes, those in the two flanges should not be placed opposite one another (A, Fig. 13, Plate 47). When a flange is of moderate breadth, say, 4 inches or less, the rivets may be placed all in one line; if over 4 inches, they should be slightly zigzagged, or "reeled," as it is termed (B, Fig. 13), the better to distribute their binding effect; if very wide, say, 6 inches or more, there should be two rows of rivets (C, Fig. 13), arranged zigzag, each at, say, 30 per cent. greater pitch; or the pitch of the row next the toe of the bar may be reduced, and that of the others correspondingly increased (D, Fig. 13), the better to secure watertightness and avoid the bursting effect of corrosion.

Art. 302. The **riveting of the shell landings** binds the different strakes into one continuous surface, so that stresses, in whatever direction they may act, are at once distributed over the whole. And, as already noticed, it is this riveting that prevents a communication of the weakness of contiguous end joints not directly over each other. When a vessel is subjected to longitudinal bending forces, the strakes of shell plating tend to slide over one another, both longitudinally and vertically; and the riveting of the landings, in resisting this movement, is subjected to shearing stress. This straining tendency of the strakes is the same as that which prevails in the horizontal layers of the beam shown in Fig. 2, Plate 114. Both straining tendencies, vertical and longitudinal, become more intense towards the neutral axis, or mid-depth of the hull; they are cumulative; the sheer strake has the least tendency to slide fore-and-aft and downwards over its neighbour; the next has a greater, because, combined with its own tendency, it is affected or impelled by that of the sheer strake; finally, the strakes next the neutral axis have the maximum tendency. Further, as in the case of a uniformly loaded beam, the straining tendency, and consequent shearing effect on the landing rivets, becomes more pronounced towards the vessel's ends. This circumstance indicates the necessity of maintaining all fore and aft the full strength of the edge riveting; it is sometimes thought permissible to reduce it towards the ends, where the plating is thin, but Lloyd's rules specify that, when double riveting is required amidships, it shall be carried all fore and aft; and in vessels 480 feet in length it is now required that the landings towards the bow and stern shall be treble riveted for one quarter the length, but only those near mid-depth, where the above straining tendency is at a maximum (Plate 90); and in vessels between 450 and 480 feet in length, additional riveting is required in the landings at these places. It should be observed that, in resisting the above fore-and-aft straining tendency of the strakes, the edge riveting is not much assisted by the numerous cross frames, for in this direction these are not rigid, and the smallest lateral yielding is sufficient to permit of serious fore-and-aft straining of the rigid rivets in the landings. Further, while

the end joints towards the bow and stern become less and less liable to stress, the landings become more and more subject to it, and, consequently, the riveting of the former need not really be more extensive than that of the latter at these places.[1]

In **wood ships the strakes of planking** are only held together indirectly by the frames, to which they are bound, for the most part, by wood treenails. Having, therefore, no real continuity, the rigidity and strength of the surface is very poor; when the hull is subject to longitudinal bending forces, the various planks are free to slide endwise relatively to one another, as in the beam in Fig. 2, Plate 114. The friction of the caulking between the planks represents, in feeble measure, the frictional resistance of a riveted joint, and confers considerable stiffness and rigidity on the entire hull; it is found, for instance, that when the caulking of a wood ship becomes soft, the hull strains and alters shape more readily.

The **shell landings**, if the plating is very thin, are **single riveted**; if over $\frac{7}{20}$ inch, Lloyd's rules require those on the bottom and bilge to be **double** riveted; and if over $\frac{9}{20}$ inch, all of them. Double riveting is first required on the bottom because of the greater exposure of this part to local stresses through grounding, which, calling for uniformity in strength, requires higher efficiency in the joints. The sheer-strake landing is double riveted in all vessels. As just seen, Lloyd's rules now require the landings at mid-depth, towards the bow and stern, to be **treble** riveted in large vessels. And in some exceptionally large vessels, having wide strakes, those of the bilge and sheer strake are also treble riveted, which assures that the end joints of these strakes shall not communicate by loosening the landing rivets. The doubling or double riveting of the gunwale bar in large vessels secures the same result as regards the sheer strake and deck stringer (Art. 115). In the earlier iron vessels the shell landings were single riveted (they were so in the s.s. *Great Eastern*), but in these the frames were close together, and as the strakes were very narrow, the end joints did not each form a long line of transverse weakness; and, further, the longitudinal bending stresses were comparatively small in these vessels, for they had fine lines and carried little dead-weight.

Art. 303. Unimportant shell landings, such as those of the side plating of deck erections, are single riveted; but if the superstructure is long, and is intended to assist the hull below, they are double riveted. At the **ends of a bridge house** the **sheer strake** is liable to intense local stress, due to the sudden stoppage of the bridge side plating, a circumstance which is provided against by doubling the sheer strake at this part. But not only is the sheer strake, at this part, liable to excessive stress, but the **rivets in its upper edge**, connecting it to the bridge side plating, are liable to intense shearing stress; for the longitudinal stress affecting the sheer strake tends naturally to distribute itself upwards into the bridge side plating, and this, of course, it can only do through the medium of the landing rivets connecting the two parts. That this is so will be evident when it is considered that if there were no landing rivets in the upper edge of the sheer strake, the bridge side plating, being disconnected, could not share in any of the stresses affecting the shell plating below; whereas, of course, when united thereto it forms the upper layer of the hull as a large girder, and suffers even more stress than the sheer strake itself. The bridge side plating is thus capable of assisting, and, indeed, is forced to assist, in resisting bending of the hull, but at its ends all of the resistance which it offers must be passed down to, and taken up by, the sheer

[1] An interesting paper on this subject will be found in Dr. Bruhn's contribution to the *Trans. Institution of Engineers and Shipbuilders in Scotland* for 1902.

strake, and this transference, of course, can only be made through the rivets in the landing connecting the two parts. In practice the prevalence of excessive stress in the riveting of the landings at the ends of a bridge house is (unless they are double riveted) constantly observed. In vessels even of moderate size it is common, where the landings are single riveted, to find some of the rivets at this part loose, and not only at the end of the bridge, but at other points of similar discontinuity, such as the ends of bulwark doors and cargo ports.[1] This weakness is now avoided by double riveting the landings of the bridge side plating at each end, as shown in Fig. 13, Plate 15. Precisely the same straining tendency prevails in the deck plating at the ends of large hatchways, which, as discontinuities in the deck plating, are homologous with the ends of the side plating of deck erections, *i.e.* the riveting of the seams, just beyond the corners of the hatchway, is subject to special shearing stress. This is well checked by fitting doubling patches around the corners, as shown in Fig. 23, Plate 58, and Fig. 4, Plate 86 (Art. 158).

Art. 304. When strakes of plating are doubled with a view to increasing their longitudinal strength, **the joints** of the two thicknesses should, of course, be as thoroughly connected as if each stood alone (Fig. 21, Plate 50). Even in so fundamental a matter misconception sometimes prevails, it being thought that, as the one strake covers the joints of the other, it takes the place of, and serves as, a strap; or that a less powerful strap may suffice. This, of course, is absurd, for with no strap the two strakes would be reduced at every joint to one; or, with an imperfect strap, to something less than two. To double a strake and omit the butt-straps would weaken rather than strengthen the structure, for as the sectional area at each joint would be reduced by half, each joint would form—like a notch in a stick—a point of marked relative weakness, and, in consequence, would suffer intense local stress. Of course, when plating not subject to severe tensile stress is doubled locally, merely to increase its lateral stiffness (as when the bow plating is doubled to resist impingement with ice, or to give a flush surface for the rub of the cables or anchors), the straps may be omitted in both thicknesses.

The disposition of the rivets in a doubled strake is shown in Fig. 21, Plate 50. The straps of the inner thickness are placed inside, and those of the outer outside, so that each may be directly over its joint. To place those of the outer thickness inside (see Fig. 7, Plate 48), as is sometimes done, is improper, because, under severe stress, when the joint tends to open, most of the stress falls on the inner thickness; the strap being remote from the joint, does not give a prompt and effective resistance, and the rivets, as regards the connected strake, are in single shear. The butts of doubled strakes are only connected by single straps; but if, in the absence of a doubling, the more efficient double-strap connection should be required, then the single strap should, for the greatest efficiency, be of extra strength, for to adopt a less efficient means of jointing because of the doubling, would be to discount some of the reinforcing effect for which it is fitted. Very commonly the joints of the inner thickness are riveted up before the outer one is fitted (in any case, some of the frame rivets are usually closed, to hold it in place); this avoids some three-ply riveting, but does not, by reducing the perforation of the outer thickness, increase the strength, for, of course, all the closely pitched rivets in the joints of the outer thickness must pass through both. The two plates must be bound together by well-distributed rivets; a closely pitched (about 5 diameters) row is placed

[1] An interesting investigation of these local stresses will be found in Dr. Bruhn's paper, *Trans. Institution of Naval Architects*, 1889.

along the edge, and, in the central areas between the frames, a few *tack rivets* are introduced. Care must be observed in riveting double plating that the two surfaces are drawn into close contact throughout, and to ensure this, and avoid puckering, the central rivets should be closed before the marginal ones; and more especially is this the case with curved plates, such as the bilge strakes. Particular care must be observed to secure fair holes in the three-ply riveting of the joints, frames, and gunwale bar; and for this purpose it is well, especially in thick and important parts, that the holes of the middle thickness should be punched small and rimered to size after the parts are put together (see C, Fig. 3, Plate 52, and Art. 306).

Art. 305. Punched holes are not cylindrical, but slightly conical, a form which is advantageous as regards the efficiency of the riveting. The taper is due to the circumstance that the hole in the *die* or *bolster* of a punching machine must be a little larger than the punch; because in the up-and-down movement of the latter there is always more or less side play, and some clearance is, therefore, necessary in order that its edge may not foul that of the bolster and cause damage to both (see Fig. 5, Plate 52). Further, if the hole in the bolster were just the size of the punch, a greater pressure would be required in punching, which, besides reducing the endurance of the punch, would increase its injurious effect on the material of the plate (experiments show that the maximum pressure required of the punch is much the same whether the hole in the bolster be large or small, but the average pressure, or work done, is greater when it is small; see *Engineering*, December 27, 1895). In punching a hole, the actual work of extrusion is accomplished before the punch is half through the plate, but to ensure that the "*burr*"—the cylindrical disc of metal—is ejected, it is made to pass right through and into the bolster. To facilitate the passage of the punch through the plate, it also is slightly tapered, from its face upwards.

According to the clearance allowed in the die, the hole in the plate may be more or less conical; if the clearance is too great, however, the edge of the die does not shear the lower edge of the hole; the action is then a tearing one, and results in a jagged projection, or "rag," around the hole (see Fig. 6, Plate 52). The clearance allowed varies considerably; the average is about one-sixth of the thickness of the plate, giving $\frac{1}{8}$ inch for $\frac{3}{4}$ plates and $\frac{1}{16}$ inch for $\frac{3}{8}$ plates. But in practice, with plates and bars of varying thickness, and punches of different sizes, no great nicety is observed; and within certain limits the precise clearance is unimportant. Sometimes, however, great carelessness is displayed in the matter of punches and dies; the die may be much too large for the punch, or the edges of both may be chipped and blunt, producing in either case an objectionable rag around the hole. Or the die may not be concentric with the punch, or the latter may have too much side play, causing twisted holes and a one-sided rag (Fig. 7). Of course, when the holes are countersunk these defects disappear, but, if not, the rivet heads cannot bed properly on the plate (see Figs. 9 and 10, and D, Fig. 11).

Several **kinds of punches** are shown in Fig. 8, Plate 52. The ordinary *flat-ended* punch (Fig. 5) is practically the only one employed in shipbuilding. The *sloping-faced* and *spiral* varieties (B and C, Fig. 8) are found by experiment to have a slightly less injurious effect on the steel, for as they cut or shear their way gradually through the plate, the pressure is at no time so intense as with a flat-ended punch; this circumstance, however, has little practical value, and as punches of this type are not easily kept in order, they have met with little or no favour. The *finder-point* punch, shown at A in Fig. 8, is advantageous where great precision

is required, for, when the centre of the hole about to be punched is marked previously with a centre-punch dab, the finder point, by engaging with the latter, acts as a guide. In punching holes with an ordinary punch perfect precision is unattainable, even if the holes are neatly marked, which, as a rule, they are not. The finder-point punch is only useful when the centre of the holes can be accurately marked by centre punch, and as in ship work this is seldom practicable, it is little used; for boiler and bridge work, however, it is often employed. Another punch sometimes employed for very thick plates is shown at D, Fig. 8. It appears to penetrate the plate more easily than a flat-ended punch, the maximum pressure being small, due to the fact that the rounded central part breaks up the steel in advance of the cutting edge.

Art. 306. In **comparing drilled with punched holes,** the fact that the latter have a natural taper is advantageous as regards the efficiency of the riveting, for as the taper is really a slight countersink, the shank of the rivet holds the parts together independently of the head or point.[1] This is often observed where rivet heads may be accidentally broken off, or where the heads of the shell rivets on a vessel's bottom may be worn away, the shanks, in either case, forming immovable watertight plugs; if the holes were drilled and parallel, the rivets, in the absence of their heads, might fall out. Of course, to secure this benefit, it is essential that the taper of the holes should face outwards, or, as it is expressed, "*the plates, etc., should be punched from the faying surface*" (B, Fig. 12, Plate 52). This is also necessary in order to ensure a close joint and sound rivets, for if the holes were reversed (as shown at A, Fig. 12), the shank might not (with careless riveting) be staved up sufficiently to swell in the middle and fill the hole; and the burr which exists more or less around all punched holes might prevent close contact of the plates, and thus destroy the frictional resistance of the joint. In a drilled hole the parallel shank is not so likely to be thoroughly staved up as in a punched one, for the latter opens outwards to the hammer blows. And, further, a rivet in a parallel hole is more likely to stretch under stress, for it is only held by its somewhat distant head and point, whereas in a punched hole the shank, being enlarged both ways, is locked, as it were, against stretching. In three-ply riveting the fact that, with punched holes, those in the central thickness are not cylindrical (Fig. 3) is a serious disadvantage; in order that the rivet shanks may entirely fill the holes, those in the central thickness, in important parts, should be punched small and rimered to size when the parts are in place (see C, Fig. 3).

Art. 307. Formerly, **rivets** were manufactured of the same diameter throughout (see E, Fig. 3, Plate 53); now, excepting very small rivets, the **neck,** or part of the shank immediately under the head, is slightly **tapered or swollen** (C, Fig. 3), so as to fill the natural countersink of the punched hole. In small rivets the swelling is a mere fillet, but in others it is a well-formed cone. If, in a large rivet, the neck were not tapered, the staving effect of the hammer blows on the distant point might not cause it to swell sufficiently to fill the hole just under the head (B, Fig. 11, Plate 52), and if, in a watertight joint, the rivet head did not bed tightly on the plate, water might find its way through this plate by the ill-fitting neck. It should be observed, however, that when the riveting is properly performed the staving effect of the hammer blows is usually sufficient to close every crevice of the holes to be filled, whether the neck

[1] Scott Russell stated that in some vessels he built the shell rivet holes were not countersunk, but had only the natural taper due to punching with a large die.—*Trans. Institution of Naval Architects*, 1887, page 308.

of the rivet be straight or conical, this being proved by the experiment of cutting riveted joints in two through a line of rivets. There is a chance, with tapered, swollen, or cone-necked rivets, that, should the swelling be greater than the natural taper of the hole, the head may not bed close upon the plate (see C, Fig. 11). To avoid this, therefore, the head should be well "laid up," *i.e.* immediately the hot rivet is inserted it should be struck several hard blows, so as to shape its neck to the hole and drive its head home on the plate; the head is not struck after the final clinching of the point, for the shock might loosen the latter.

Art. 308. Rivets are designated by the form of their head and point. Fig. 2, Plate 53, illustrates various **kinds of heads,** the dotted lines show their form before riveting, and the full lines their form when finished.

The **pan head** is the one most used (A, Fig. 2, Plate 53), the others being employed only for special purposes. It possesses the important quality of strength, for it is massive, and its large bearing shoulder has a good clamping effect on the plate. The watertightness of a pan-headed rivet is assured by the bearing shoulder of its head, and by its plug-like tapered neck. It is easily held up during riveting, and its soundness is readily tested (Art. 316). During the process of riveting, the repeated blows of the holding-up hammer tend to expand and flatten the head, especially if it be soft and hot, and so, in order that it may not become too flat and button-like, it should evidently be deep to begin with. Depth and substance are important, for, under an excessive stress tending to distort the joint, the rivet heads tend to yield by a curling up of the shoulder (Fig. 1, Plate 48), an effect which, of course, is minimized by making them substantial. Pan heads differ considerably in their relative proportions: the older type—still employed by the Admiralty—is shown at D, Fig. 3, Plate 53; the one now generally adopted in merchant vessels, and as specified in Lloyd's rules for the shell plating, is shown at C, Fig. 3.

The **snap head** (B, Fig. 2, Plate 53) is practically only used in machine riveting, for with hand riveting two men are required to hold up, one to hold a *snap tool* (Fig. 8) on the rivet head, and the other the holding-up hammer on the tool.

The **countersunk head** (H, Fig. 3, Plate 53) is employed where a flush surface is required, as in keels, etc., or in gunwale and other bars against which deck planks or woodwork is fitted. It is also used in places where watertightness is essential but not readily secured. It may or may not be perfectly flush; when it is (F, Fig. 2), it must be chipped and finished off with small hammers in the same way as a countersunk point. Where a perfectly flush surface is not necessary, it should be made sufficiently deep to project beyond the flush (G, Fig. 2), otherwise the holding-up hammer would not bear properly upon it. The taper of the head should, if anything, be sharper than the angle of countersink of the hole, so as to ensure the bottom part filling the countersink; the outer portion of the head is, of course, readily expanded by the hammer blows (see H and I, Fig. 2). The cone-like formation of a countersunk head makes it very efficient as regards watertightness, and as it reduces the length of the rivet shank, it is specially suitable for watertight three-ply riveting, such as occurs in tank work. Its watertightness is assured almost independently of the efficiency of the holding up; a pan head, on the other hand, must be well laid up, so that the neck of the rivet may fit plug-like in the hole, and the head bear uniformly all round, a perfection the attainment of which in inaccessible places is not always certain. In view

of their assured tightness, countersunk-headed rivets were tried for the shell plating, etc., of oil vessels, but they were not found to be advantageous. To employ them extensively involves extra work in countersinking; when used in bars, the material removed by the countersink reduces the sectional area of the flange, and they have the considerable disadvantage of not being readily tested.

With **flattened countersunk heads** (C and D, Fig. 2, Plate 53) the holes are not countersunk; usually, however, the natural countersink due to the punch is increased by the use of an extra large die. When finished this rivet head resembles a large flat button. In some yards "Bull-headed" rivets are preferred to countersunk ones for this work (I, Fig. 3); they are advantageous in that the head is deeper when finished (L, Fig. 2). The advantage of this class of rivet head lies in the fact that, as the bearing shoulder is formed by the hammering, watertightness is assured despite irregularities in the holding up. It is, therefore, a convenient rivet to use in awkward places, where it may be difficult to hold up, and yet where watertightness is essential; thus, it is often employed for the riveting in the confined space of a double bottom, for the tank top, margin plates, etc. As regards strength, it is not an efficient type of head, for it is too thin to give a substantial clamping effect; its use should, therefore, be confined to parts not structurally important. It is often employed for the framework of light-scantlinged paddle steamers, etc., for it is light, and its large area distributes its clamping effect on the thin material. In some cases it is used in holes slightly countersunk (E, Fig. 2).

Plug-headed rivets (J, Fig. 2, and Fig. 3, Plate 53) have never had an extensive use, they are found to be defective in clamping power, and are now rarely employed. A plug head is practically a pan head with the shoulder removed, and the advantage claimed for it at one time was the assurance that the head, being a tapered plug, could be driven into the hole with a special degree of solidity and tightness. But with well proportioned pan-headed rivets, the tapered neck fits with no less solidity, and they have the advantage of a large bearing shoulder, which not only distributes and increases the clamping power of the rivet, but, under a severe stress, tending to strain and distort the joint, checks the side-tripping and loosening effect on the rivet. When subjected to intense stress, steel behaves like a plastic substance; and so the large projecting plug-head, having little bearing on the plate, may draw into the hole and, by tripping sideways, accommodate itself to the straining of the joint. A plug-headed rivet may be loosened by striking it a heavy blow on the head. In process of hammering up, a slight shoulder becomes indented around the head (see J, Fig. 2); and if the latter is well heated, so as to secure a large bearing shoulder, it would assume, in some measure, the excellent characteristics of a pan head.

Art. 309. Rivet points of various kinds are shown in Fig. 1, Plate 53. The **hammered point** (E, Fig. 1) is the most readily made, for it is expeditiously clinched and requires no chipping. As regards strength, there is little differenee between it and a countersunk point. The length of the rivet should be such as to provide sufficient material, because, when too short, the point, as shown at G, Fig. 1, is small and button-like; it should be a well-formed flat cone, and, preferably, its sides should be slightly rounded (F, Fig. 1). This point is used for nearly all internal work not requiring a flush surface. It is sometimes employed for tank tops and even for decks; but countersunk points of full type are preferable for these parts.

The **snap point** (H, Fig. 1, Plate 53) is not much used, and, as it is not an efficient one, only for parts not subject to severe structural stresses,

such as bulkheads, casings, etc. On account of its pleasing, symmetrical appearance, it is suitable for parts exposed to view, in passenger accommodation and in the engine space. To form it, the rivet point is first staved up, by squarely-directed hammer blows, until the shank grips in the hole, whereupon a snap tool (Fig. 8) being held upon it and struck a few heavy blows, results in a smooth, polished, hemespherical point. It is not a reliable point, for instead of receiving a series of direct blows, each one staving it up more and more solidly, many of the blows may expend their energy on the plate alongside, especially if the rivet be too short (I, Fig. 1), a circumstance indicated by the marks made upon the plate by the edge of the snap tool; and, moreover, the point is not always concentric with the shank. Very small rivets, $\frac{3}{8}$-inch and less, are closed cold, and in such cases the point is usually formed with a snap tool. In small steel boats, such as are employed on tropical rivers or lakes, the shell rivets are often formed with snap points, because, to countersink and flush rivet plating thinner than $\frac{1}{8}$ inch, would give very unsubstantial results. Small rivets of good, soft quality, whether of steel or iron, may be moulded cold with perfect ease under the hammer, suggesting, in their behaviour, lead rather than steel.

The **countersunk point** (A, B, C, and D, Fig. 1, Plate 53) is the most efficient; experiments with riveted joints show it to be the best, both as regards frictional resistance and ultimate strength;[1] and it tends to sounder work, for as the length of the rivet shank requiring staving is reduced by the countersink, the solidity of the finished rivet is more assured. The point may be finished off quite flush, slightly convex, or full, like a hammered point. Those in the under-water part of the shell should be slightly convex (see B, Fig. 1), so as to provide substance for corrosion, for the rivet points are often found to corrode faster than the surrounding plate. In other places they may be finished off quite flush; a slight fulness is generally advantageous, but to so form them requires more time and care on the part of the riveters, which, unless insisted upon, are not always bestowed. The points and heads of the keel rivets are, of course, countersunk, and they are usually left specially full. The points and heads of the rudder rivets are peculiarly liable to corrosion: formerly they were of snap type, but as these were found to disappear rapidly and leave the plates loose, they are now always countersunk, and, in addition, made full, like a hammered point (see C and D, Fig. 1). In deck and tank-top plating the rivets have usually countersunk points, and in some cases they are left full, like a hammered point (D, Fig. 1), which is advantageous in the case of thin plating, where a flush, countersunk point might be insufficiently substantial. In the case of an unsheathed plated deck, projecting rivet points are advantageous in improving the foot hold.

Art. 310. In countersunk holes, the **depth and angle of the countersink** are matters requiring consideration. Lloyd's rules require the countersink to extend right through the plate when this is less than $\frac{14}{20}$ inch thick (Fig. 1, Plate 50); when $\frac{14}{20}$ inch thick and above, it need only extend through $\frac{9}{10}$ of the thickness (Fig. 2). The rules of the British Corporation require it to extend right through the plate; and those of the Bureau Veritas require it to extend at least two-thirds through (Fig. 3). A through countersink is advantageous in that it ensures the removal of the greater part of the material damaged by the punch. The work of countersinking is done in a rough-and-ready fashion, and, to save time and reduce the work of clinching the rivet points, there is a natural tendency on the part of the workmen to make the countersink small and shallow, a circumstance

[1] Wildish, *Trans. Institution of Naval Architects*, 1885, page 190.

which is well provided against by the unequivocal requirement that it shall extend right through the plate. As regards strength, if the plates are fairly thick, a countersunk point, only two-thirds through, is quite as strong as one completely through, and in boiler work this is the usual proportion, but here the holes are drilled and the countersinking is carefully done. Contrary to what might be supposed, the sharp edge of a through countersink does not lower the shearing resistance of the rivet, for this is found to be practically the same whether the hole has a sharp edge or a square shoulder. It should be observed that the sharp edge does not act like a chisel, for when the joint is strained so as to shear the rivet, the plate and rivet point move as one, so that the contour of their buried surfaces is immaterial. In thin plates, a through countersink is desirable for the strength of the rivet point, so that it may not be so slender as to break or pull through the plate, and to provide substance against corrosion. It has also the advantage of allowing unfair holes to be more readily faired, and, by reducing the length of the rivet shank, it conduces to sounder rivets.

The angle of countersink is greater in thin plates than in thick (see Fig. 4, Plate 50), for in the former the rivets are relatively large and strong, and so, to give them a sufficient grip of the plate, their points must be large or obtuse: if too acute, they might pull through the plate (see Fig. 22). In cases of damage by collision, where the forces are irresistible, or where, as in old vessels, rust has accumulated between the faying surfaces, it is common to find that thin plates have pulled over their rivet points. On the other hand, the angle of countersink should not be too great; for the edge of the rivet point might be so thin and knife-like as to have little endurance, and, in clinching it the hammer blows might not caulk it tightly, in which case, water having access, it would soon be eaten away by corrosion. The general practice, and that specified by Lloyd's rules, is to make the face diameter of the rivet point $1\frac{1}{2}$ times that of the punched hole; the resulting angles are shown in Fig. 4. With plates of varying thickness it would, of course, be difficult to conform exactly with this rule, but departures therefrom, if moderate, are unimportant.

Art. 311. As the ends of the **buttstraps of** the **outer strakes** of shell plating are not fitted with any great precision against the edges of the contiguous strakes, there exists at each end an aperture more or less minute, through which, before caulking, the eye may often see daylight (see Fig. 14, Plate 47). In some of the earlier iron vessels it was thought necessary to cover these points, either by joggling the strap over the landing, or by fitting short covering straps over all (see A and B, Fig. 14). This, however, was soon found to be unnecessary, for a small discontinuity in the backing-up material does not affect the watertightness of the caulking on the outside. Of course, with a badly-fitted strap and an open or corroded butt, the watertightness may be only that due to the choking or cementing effect of corrosion. In oil vessels, ordinary inside straps are inadmissible; for not only is oil more searching than water, but it precludes the formation of rust, with its valuable leak-stopping properties.[1] In these vessels the shell joints may only be butted if the straps are placed outside, this disposition admitting of very perfect caulking. In the case of boilers, the existence of the above small uncovered apertures in butted joints is incompatible with steam-tightness, and so the ends of the straps, instead of being

[1] It is a curious thing that corrosion is sometimes found in the tanks of oil vessels. It occurs, no doubt, during the periods when the tanks are used for water ballast. It is found chiefly in the bottom shell plating, the outer strakes being sometimes corroded in a fore-and-aft channel, close to the edges of the inner strakes. For this reason it is now sometimes thought proper to cement the bottom shell plating, as in ordinary vessels.

stopped short against the edge of the contiguous plates, are tapered and inserted below them, suitable recesses being formed for their reception; and in some cases the butted edges are welded together at these points.

Art. 312. With ordinary **lap joints, tapered liners** are fitted to make good the vacancy at either landing, where the one plate overlaps the other (see Figs. 1 and 2, Plate 51). They are usually made sufficiently long to take three of the landing rivets, *i.e.* from 9 to 12 inches, and as their tapered ends should be kept clear of the adjacent frame (so that their displacing effect on the outer strake may not occur **at** the frame, and thus involve the fitting of special frame liners) they preclude the placing of the lap joint in the centre of the frame space. In fitting them, care should be taken that the thick end abuts in close contact with the end of the plate, so that it may be caulked without the insertion of a filling piece (Fig. 23, Plate 93); and they should be uniformly tapered to a thin point, so as to avoid objectionable irregularities in the shell.

Lap joints are now very generally fitted in the superior manner illustrated in Figs. 3 and 4, Plate 51. Here, **tapered liners** are **dispensed with**, for the plate itself is tapered, in a slotting machine specially designed for the purpose. Formerly the thin plating of decks, bulkheads, tank tops, etc., was sometimes tapered in a similar way; but it was done in a very imperfect fashion by heating the corner of the plate and thinning it down on an anvil, and sometimes it was done cold, but then the taper was still more imperfect (Figs. 8 and 9, Plate 89). The inner boundary of the tapered part of the shell plates may be cut square, so that the edge of the continuous strake may abut upon it (see Fig. 5, Plate 51); or it may be bevelled or hollowed off with a gouge-shaped tool, so as to permit of edge caulking and avoid the necessity for perfect accuracy in the fitting of the edge of the contiguous strake (see Figs. 4 and 6). The latter plan is the one generally adopted. The former is advantageous in that, *if* the contiguous strakes are accurately fitted, it admits of more substantial caulking, for in the latter there is a small exposed point (P, Fig. 4) in the knife-edged part, which cannot be substantially caulked, and which, if the vessel's bottom were not kept well coated, might soon be eaten away by corrosion. Even if this happened, however, it would not result in leakiness, for the formation of rust between the faying surfaces would preclude the passage of water.

The tapering of lapped joints is advantageous in that it dispenses with clumsy liners, which add weight, involve extra three-ply rivets and caulking, and prevent the joints from being placed mid-way between the frames. And further, a plated surface, so jointed, is much fairer, for, as shown in Figs. 3 and 4, Plate 51, the landing edges of the contiguous strakes do not deviate from a fair line in way of the overlap. With liners, the landings appear to be full of lumps and hollows (see Figs. 1 and 2), so that it requires a practised eye to detect unfairness due to other causes. In the actual work of making these joints, the slight knuckle shown at K, Figs. 3 and 4, is sometimes impressed on the plates before they are fitted and riveted, a special hydraulic press being employed for those of the curved bilge strakes. As a rule, however, excepting thick keel plates, this is not done, the plates being pulled into shape only by the riveting. Contrary to what might be supposed, the rivets are not thereby placed in a condition of permanent tensile stress, for on cutting a riveted joint asunder it will be found that the plates have assumed, by the mere hammering and riveting, a permanent set, with a knuckle, sharp at the landing, but less well-defined towards the middle of the plates. It is advantageous that a lap joint should lie as shown at M, Fig, 4, for as this

is how it disposes itself when severely stressed (see Fig. 3, Plate 48), there can be little further lateral straining.

Art. 313. By the usual unprecise method of punching, the corresponding **rivet holes** in connected parts **can never be perfectly coincident** (holes of varying degress of unfairness are shown in Fig. 1, Plate 52). The discrepancy should, of course, be small, and if, say, only $\frac{1}{16}$ inch, it may be **corrected by drifting.** The *drift* (Fig. 14) is a very useful tool; it is simply a tapered steel pin, which, when driven into a hole slightly unfair, so enlarges it and strains the plates relatively to each other, that the holes in the two parts become practically fair and cylindrical. Good steel is not injured by moderate drifting; in experiments made to ascertain its endurance of the stretching and distorting effect of the drift, a hole punched near the edge of a plate may be enlarged to more than twice its original diameter without showing cracks. Excessive drifting is, of course, objectionable, for it tends to stave up the edge of the plate in the hole, so that the faying surfaces cannot lie in uniform contact (a defect often observed in the joints of badly fitted thin plating), and it may also produce internal stresses objectionable in important parts. In the case of iron plates, drifting is a severe and dangerous expedient, for the inferior material of which iron ship plates are made does not stretch like steel, it cracks and splits when subjected to the most moderate treatment.

When holes are so unfair that they overlap by about $\frac{1}{8}$ inch, the projecting edges are very commonly chipped off with a gouge, or "*picked*" as it is termed, the drift being used finally to smooth off irregularities (see A and B, Fig. 1, Plate 52, where the shaded parts represent material removed). If carefully corrected in this way the rivet may be sound and fairly efficient. As a rule, the hole in only one thickness is enlarged, this being sufficient to permit of the entrance of a full-sized rivet, and if corrected in this way it is well for the soundness of the rivet that, in the case of countersunk holes, the countersunk plate should be the one corrected, irregularities being then better filled by the rivet; this will be observed on comparing the rivets shown at F and G, with those at L and M (Fig. 1). When insufficiently corrected, an unfair hole may not admit a full-sized rivet, and riveters will then sometimes use a small one, perhaps one wasted thin in the fire, when, of course, the likelihood of its being sufficiently staved up to fill the hole is small (see K, Fig. 1).

Holes which are unfair to the extent of $\frac{1}{8}$ inch, or more, should be **corrected,** not by gouging or drifting, but **by rimering.** The tool usually employed is merely a modified drill (see C, Fig. 13, Plate 52). This tool is not an efficient one, its effect is little better than that of a gouge, for it only removes material from one thickness, making the hole in this plate oval. To secure perfectly fair holes, a rimer such as that shown at A, B, D, or E, Fig. 13, should be employed. The imperfect fairing effect of rimer C is shown at A, Fig. 2, where it will be observed that only one of the overlapping shoulders in the unfair hole is removed, making the hole in this plate oval. In using a rimer it should be passed sufficiently into the hole to enlarge that in both plates, leaving both circular (see B, Fig. 2); it should, therefore, be of large size, more or less according to the degree of unfairness. A portable pneumatic hand drill is now sometimes used with advantage for rimering unfair holes in the shell and other parts (the rimering tool generally used with it is shown at E); it does its work both quickly and well. A "*half-blind*" hole is one in which the holes in the two parts half overlap each other (see D, Fig. 1); and it is evident that unless its diameter is increased by 50 per cent. it cannot be made cylindrical. Holes so unfair should, of course, never occur, but when by

accident they do, the expedient adopted is to pass through a large rimer, and use an extra large rivet, or one having a neck specially enlarged to fit the oval hole. When holes are countersunk, unfairnesses may sometimes be well corrected by enlarging and deepening the countersink (see C, Fig. 1). It should be observed that the rimer should not be used until the parts are tightly screwed together ready for riveting, so that there may be no chance of the drillings entering between the faying surfaces and thus precluding close contact and sound riveting; otherwise the parts should be sprung asunder, after the rimering, to remove the borings.

Unfair holes are most **prejudicial** to the efficiency of the riveting, for it is evident that rivets, such as those shown at L, M, N, J, and K, Fig. 1, Plate 52, can give but poor resistance to straining of the joint. It should be observed that the defects shown in the rivets at J and K are exaggerated, for if the rivets were well closed and hammered up the vacancies shown in the sketches would be much smaller. The impracticability of ensuring that every punched hole shall be quite fair, is a reason for introducing in important joints more rivets than would be justified merely by a consideration of their combined shearing strength. In good work, there should be no holes so non-coincident as not to be capable of being well faired by moderate drifting. If, in any one part, there should be a considerable number of unfair holes, the part should be rejected as unfit for a high-class structure. It has sometimes been urged that, to ensure perfect riveting, all holes in the shell plating should be drilled, as in a boiler; but this would greatly increase the cost and time of construction, and, as already noticed, punched holes have some mechanical advantages. Nevertheless, in important parts, such as the sheer strake and upper-deck stringer of large vessels, the plan of systematically drilling or rimering the holes in place is sometimes advantageously adopted; the work being expeditiously and economically performed by the use of portable electric or pneumatic drills.

Art. 314. Whatever the **form of a plated surface**—fair or otherwise—before riveting, it is **rendered fixed and permanent by the riveting.** So long as conjoined plates are not rigidly united, they may be bent laterally by the application of a small force, and if, when so bent, they are riveted, they will retain their relative position or form. When handed over to the riveters, a plated surface may be lumpy and irregular, especially if the plating is thin; and as they are responsible for its final fairness, their first operation is to set it fair, by bolts, wedges or shores. In many yards, however, the riveters are relieved of this duty, a special set of men being employed to screw up and fair the plates before they start to rivet them (Art. 527).

The **rivets are heated** in small portable hearths. They are placed point downwards in the fire, so that their heads may remain comparatively cool, for, if hot like the point, they would flatten too much under the hammer. Very commonly a perforated plate is laid on the fire, so that the points only of the rivets (each one placed in a hole) may receive the full effect of the blast. They should not lie too long in the fire, for they thin away by oxidation, and may deteriorate in their mechanical qualities. In the case of large iron rivets, the point may be heated almost to a plastic welding temperature, but small ones need not be so hot. Steel rivets if heated to the same high temperature would be very near the burning point, at which they would be seriously injured; they are, therefore, not worked so hot as iron rivets (Art. 319).

A **rivet squad** consists of three men and one or two boys; one of the latter heats the rivets, the other conveys them to and inserts them

in the hole (if there is only one boy, he may merely throw the rivets to the holder-on), two of the men clinch the point, while the third "holds up" the head. Riveting hammers are illustrated in Figs. 15 to 21, Plate 47, their weight varies from 3 to 8 pounds, according to the size of the rivet and its location. Parts about to be riveted must first be pulled perfectly close together by numerous bolts ("service bolts"), for the rivets cannot be depended on to draw them together, and, if not close, the hammering may stretch the parts and alter the form of the surface, the one plate creeping over the other. Very long plates should be fixed in place by a few well distributed tack rivets, to prevent creeping action during the riveting; and they should be riveted up from the centre towards the ends. In the region about to be riveted, bolts are placed in every second or third hole, so as to secure absolute contact of the faying surfaces; for if these were not quite close, the hot rivet would have to pull them together, and this, through bulging of its shank, it might not do. To save labour and expedite the work, riveters are inclined to use fewer bolts than is desirable for the assurance of thoroughly close work.

The **procedure of closing a rivet** is as follows: the hot rivet being inserted in the hole, the *holder-up* strikes the head a few blows (to lay it up, so that it may bed fairly on the plate) and then holds it up with the hammer ("*holding-up hammer*," Fig. 15, Plate 47) against the blows rapidly delivered on the point. At first, the point is struck fairly, end-on, so that the shank may be staved up and fit tightly in the hole throughout its length right up to the head; if it is a countersunk point and the rivet shank is rather long, it is then struck towards one side, so as to bend it over in such a way that the surplus material, not required to fill the countersink, may all bulge to one side, and thus be readily chipped off while still hot. After chipping off the rag, the rivet is allowed to stand for a few minutes until it has cooled; it then receives a second series of blows, delivered with care, all around the edge of the point, which caulks it and—in good work—finishes it off so smoothly as to make it difficult to discern any precise line of demarkation between rivet and plate. The period between the first and second series of blows is occupied in giving a second series to the last rivet dealt with, and in drifting the hole for the next and clenching it as just described. If the final series were delivered immediately after the first, the rivet, when finished, being still hot, might be loosened by the contraction in the diameter of its shank and point, and by the subsequent drifting of the adjacent hole and hammering up of the rivet. After the first series of blows, the rivet point usually shows a slightly bluish temper colour (especially if it be a steel rivet), and the second series, if given at the proper time, when the rivet is cold, should dissipate this, *the finished point showing no colour*. In very hot weather, when the rivets cool slowly, it is advantageous, with large rivets, to delay giving the final series of blows until two others have been clinched. While giving the final series of blows, the plate also is struck, along the edge and between the rivets, so as to bring the faying surfaces everywhere into close contact, this being an important condition and one specially looked to when the work is subsequently examined and tested. Riveting work is prejudiced by wet weather, for when water gets between the faying surfaces of the joint it chills the hot rivet shank, and the film of steam which forms alongside prevents close contact of the faying surfaces.

The rivets on the flat of the bottom are awkwardly placed for hammering up; in heavy work, long-shafted **heavy hammers** are employed for dealing swinging blows at arm's length, small "*set*" or **caulking**

hammers, having a slightly bevelled face (Fig. 17, Plate 47), being used to finish off. The riveters on the north-east coast of England use only one hammer, a fairly heavy one. For keel rivets, large hammers are employed, and after the point is clinched both it and the head are finished off as just described. In shell riveting, a section, or berth, is allotted to each of the numerous rivet squads. The usual procedure is to rivet each landing consecutively, beginning with the garboard strake, the particular one dealt with being first carefully faired, as described in Art. 527. The rivets are then hammered up consecutively, the frame rivets, as they occur, being also taken, but only those in the vicinity of the landing, from centre to centre of each strake. In riveting a long plate, the large amount of hammering it receives tends to stretch it slightly, a circumstance which may affect the fairness of the holes and cause buckling; to preclude this, it must be tightly clamped in position by numerous bolts. The elongating effect of the riveting is sometimes a convenience; in the case of butted joints, for instance, which do not fit quite closely, they may be brought together by first clinching the outer rows of rivets. Similarly, in riveting the landings, angle bars, etc., the stretching effect of the riveting may be a useful means of adjustment for unfair holes. Many rivets are so situated, behind reverse frames, stringers, etc., that an ordinary holding-up hammer cannot be used. For these a "*dolly*" is employed (see Fig. 18, Plate 47). This is simply a massive bar, having an elbow and an enlarged or bevelled end, such that, while the latter rests squarely on the rivet head, the bar clears the obstruction. With large rivets, a second workman may apply a holding-up hammer to the end of the dolly. For the shell rivets of channel frames, a holding-up hammer of modified form may be used in the ordinary way (see Fig. 21). The rivet heads on the under surface of horizontal plating—decks and tank tops—are held up as shown in Fig. 19, by a long-shafted hammer, suspended by a hook (or as shown in Fig. 20) and used lever fashion. Similar hammers are employed for riveting the masts and inaccessible places in the hull.

Art. 315. The **riveting of stern-frames**, in which the rivets may be $1\frac{1}{4}$ inch in diameter and of any length up to about 12 inches, is an operation requiring special care, for while soundness is essential, it is not readily secured (Art. 256). In hammering up a long rivet, little of the staving effect extends to the shank, it expends itself on the point, and, accordingly, if such a rivet were heated throughout its length, the contraction in its diameter due to the cooling would not, as in ordinary rivets, be made good by the subsequent hammering; the result, therefore, would be an unsound rivet, readily loosened by the jarring and vibrating effect of the propeller. But, further, the great lengthwise contraction of the shank of a long rivet might place it in such severe permanent tension as to render it liable to break across at the neck. In practice, therefore, the shank is, or should be, exactly the diameter of the hole, so that it may be a tight driving fit; and only the point is heated, the remainder being cooled in water, so that the shank, being of normal diameter, may pass into the hole. These rivets are often made in place, from long bars cut to length, one end being first heated and staved up in its hole, to form a well-fitting countersunk head. In many cases the riveting of large stern-frames is defective, due principally to the rivet shanks being a slack fit in the holes. If through rivets are employed for the bossed portion of the post, the rivet heads are formed with a very deep countersink, so that in boring the boss for the shaft tube the removal of $\frac{1}{2}$ inch or so of metal may not hurt them. The boss is bored for the tube after the shell plating is riveted, for the extensive hammering has a twisting and displacing tendency on the stern-frame. To

avoid the awkward work of countersinking these particular rivet holes, and the difficulty of renewing the rivets should they break or become loose (an operation necessitating the withdrawal of the tube), tap rivets are usually substituted at this place (A and B, Fig. 3, Plate 53).

Art. 316. All riveting work must be carefully inspected and tested, to ensure that each rivet is tight and sound, and that the faying surfaces are everywhere in close contact. Piece-work riveters are not remunerated for their work until it has been tested and found good. The **closeness of a joint** is tested by a thin-bladed knife, the insertion of which between the faying surfaces should not be possible; in bad work it may enter so freely as to encounter the rivet shanks. The joints of the plating are usually well closed, but between the frames and shell or interposed liners the contact is often more or less defective in places, especially where the frames are bevelled. If, in the case of deep, rigid frames of solid section, the bevel is inaccurate, the riveters may experience difficulty in pulling the flange and the shell plating into close contact at both toe and heel, more especially when the bevel is too great, for then, while the toe is against the shell, the more rigid heel is not. When close contact cannot be secured, the clumsy expedient is adopted of inserting feather-edged and tapered liners in the vacancies (Fig. 18, Plate 93); and sometimes strips of sheet iron are caulked in between the heel of the frame and the shell. The importance of close contact of the frames and shell plating is evident; in its absence, heavy blows from the waves might readily loosen the shell rivets. If a joint, in which the faying surfaces are not in contact, is struck by a hammer between the rivets, a hollow jarring noise and absence of sharp rebound in the hammer will proclaim the defect; after stranding, when the shell riveting may be strained, that of the landings may be conveniently tested in this way. The **solidity of the rivets** themselves may be tested by sound, by touch, or by the rebound of the testing hammer. The head or point of a tight rivet when struck by a hammer gives a clear ring, the hammer rebounding sharply; if not tight it will sound more or less cracked, and the hammer will not rebound sharply; when rivets are struck consecutively, a bad one will at once announce itself. The usual method of testing combines the sense of touch with that of sound. While the finger is held against one side of the rivet head, the other is struck a side blow with a small testing hammer; if the rivet is tight and solid the finger will not be sensible of the blow, if not perfectly tight a jar will be felt, more or less pronounced, and the hammer will not rebound sharply. They may be equally well tested by striking the head while the finger is held on the point, or *vice versâ*. A defective rivet may usually be made good by further hammering, but if this does not prove an immediate remedy, the fault is serious, and it should be renewed. Rivets which pass through several thicknesses, or whose heads may not be properly laid up, are very apt to jar under the testing hammer; and sometimes, to prevent this, the riveters will caulk (or "jag") the head locally, as shown at N, Fig. 1, Plate 52); but this, of course, is very improper, for although the jamming effect of the caulking may stop the jar, it does not improve the solidity of the rivet, it simply makes a bad rivet appear good.

Art. 317. Tap, stud, or screwed rivets are illustrated at A and B, Fig. 3, Plate 53. Their ultimate strength, as ascertained by experiments with riveted joints, is little, if at all, inferior to that of clinched or through rivets;[1] but otherwise they are less efficient, for they do not fill the holes with absolute solidity, their clamping effect is inferior, and they are liable to

[1] Wildish, *Trans. Institution of Naval Architects*, 1885.

become loose through corrosion and wasting of the thread. For connecting thin material they are particularly objectionable, for the thread, having so small a grip, may strip through stress or corrosion, or the rivets may work back and loosen the joint; when used in thin plates, they should pass right through, so that a lock nut may be hove up on the projecting point. In shipbuilding, however, their use is practically confined to the riveting of the shell plating to the stern-frame, where, if the work is properly done, the above objections become unimportant. Here they are advantageous, in that, as they are short and inextensible, they need not be so large as through rivets (their diameter is, of course, measured under the thread); the latter weaken very considerably the forging, and, as already seen, unless they are closed with the greatest care, their soundness is more or less doubtful. In certain places the use of tap rivets is inevitable, as, for instance, at the upper and lower turn of the bossed portion of the stern-frame, where an ordinary rivet would not pass squarely through the surface, and at other inaccessible places, where ordinary rivets could not be inserted or clinched.

Tap rivets should grip tightly in the screwed hole, so that they may have no tendency to slacken under side stress and vibration; to ensure this and provide against corrosion of the thread, those in the stern-frame should enter to a depth at least one and a half times their diameter, which, of course, is more than is necessary as regards mere strength against an outward pull. The countersunk head should be concentric with the shank, and it should fit truly in the countersink of the plate, for, if not, the one-sided contact would result in a one-sided straining effect, tending to break off the head. As ordinarily fitted, the head seldom fits with precision in the plate; to ensure this the rivets should be turned and the holes drilled and countersunk in place. An ill-fitting head cannot, as with an ordinary rivet, be corrected by staving it up with a hammer; such treatment would break it off at the neck. It can only be caulked on the surface, an important operation, however, in that it locks the rivet against turning back and prevents the entrance of water with its corrosive effect. The countersink in the plate must not pass quite through, otherwise the rivet would jam before it exerted a proper clamping effect. For the purpose of heaving up the rivet a square projection is provided on the head, which, of course, is subsequently cut off. Sometimes the projection is formed with a nick around its base (B, Fig. 3, Plate 53), so that when screwed up to a certain tightness the spanner may wrench it off, a plan which ensures that all rivets shall be well, and equally, tightened. In warships tap rivets are extensively used; the light angle bars connecting to the protective deck, for instance, are tap-riveted thereto, for as this plating may be several inches thick, large through rivets would be quite inapplicable (Plate 113).

Art. 318. Hydraulic riveting is superior to hand, in that there is little chance of unsound rivets, and the different parts, however stiff, may be forced into absolute contact, thus securing a high frictional resistance. The soundness of hand-closed rivets varies with the conscientious care and energy of the men, and even in careful work, if the holes are not fair, the rivet shanks may not absolutely fill them. A rivet that is closed by hydraulic power is subjected to such intense compression that the material of its shank flows almost like wax, so that even in very unfair holes every crevice may be filled. The action of an hydraulic riveter is illustrated in Fig. 19, Plate 50; the rivet head is held up by the one die of the machine, while the other, taking contact with the point, first crushes up the shank and then moulds the point in its cup-shaped recess, any excess of material oozing out as a thin collar. In order that the shank may stave up before the point, it

should be hotter, if anything, and with this in view, the points of long rivets are chilled in water. The rivets should not be hotter than a bright red, otherwise they would flow in so liquid a fashion that some of the shank material might ooze between the faying surfaces; when the parts are not screwed tightly together this sometimes occurs.

Steel rivets that are quite cold may be closed by hydraulic power, but so great a pressure is necessary (about 140 tons per square inch of rivet section), that the plate, being nipped with the rivet, may also flow and become indented; this effect may sometimes be observed in rivets situated near the edge of a plate or bar, by a slight bulging of the edge in way of each rivet. The pressure adopted in practice varies with the class of work and the judgment of those in charge. The water **pressure at the accumulator** is usually about 1500 pounds per square inch; but although fixed in amount at this, the source, the **actual pressure brought to bear on the rivets** depends on the design and dimensions of the particular machine employed—*i.e.* on the diameter of the ram and its leverage. In heavy boiler work the rivets are usually subjected to a pressure of about 100 tons per square inch of their sectional area. In ship work, as the plates, etc., are much thinner, a considerably smaller pressure suffices; 75 tons per square inch is not usually exceeded, and with this as the standard, a machine suitable for $\frac{7}{8}$-inch rivets would exert a total pressure of 45 tons. The precise pressure is unimportant, but it is well that it should be large rather than small, for although a pressure of 50 tons per square inch would be sufficient if the rivets were always red hot, it might be inadequate should they happen to be fairly cold.

The **procedure** adopted **in machine riveting** is first to screw the parts together with a bolt in every second hole for a distance of 5 or 6 feet, and when the intermediate holes are drifted, and all is ready, some ten or twelve rivets—heated in bulk, in a small reverberatory furnace—are inserted and closed forthwith, in little more than a minute. If the work is not *close*—*i.e.* if the parts do not lie perfectly close together between the rivets—the necessary contact is at once secured by nipping them together with the machine. In machine riveting it is, therefore, the preparatory work that takes time; the rivets themselves may be closed almost as fast as they are put in the holes. It is the association of expedition with efficiency that makes machine riveting preferable to hand. The work may be done too hurriedly, however; the machine may not be held squarely on the rivet, so that the shank may not be properly staved up and the point may not be concentric with the shank, and sometimes a rivet may be too short, resulting in an insufficiently staved shank or an imperfectly formed point. In heavy work—such as keel riveting—the machine should not be removed until the rivet has cooled somewhat, for if released when it is still hot and soft, the parts might spring asunder; by working the rivets fairly cold, however, the need for this delay becomes unimportant, especially with light parts. In heavy boiler work each large rivet receives a second squeeze after it has cooled. Ordinary pan-headed rivets are generally used for machine work, the finished head and point being almost invariably of snap type. If a countersunk point is required, a fairly flat die may be used, but as the point must always project somewhat (so that it, and not the plate, may receive the pressure of the machine), hand chipping and caulking are required to finish off. This necessity is a deterrent to the use of the machine for countersunk riveting. When the sheer strake is machine riveted, the points may be of snap type, for, of course, when above water, these are not objectionable.

Hydraulic riveting is adopted more or less extensively in all large ship

yards; in many, however, it is not always found advantageous as regards expedition and economy, and although machines may be available, they are not always employed. Its use is practically confined to the riveting together of the frames, reverse bars, and floors, or the component parts of built beams, deck girders, bracket plates, tank-margin lugs to margin plate, etc., for as these parts exist in large numbers, they may be brought to the machine, screwed together, and riveted without delay, in wholesale fashion. Even small riveting machines weigh upwards of half a ton, and as pipe connections must be provided for the water, they are most conveniently employed when established as fixtures, the parts of the structure being brought to them, and not they to the structure. They may be placed in any convenient spot, and are suspended usually from a small trolly or runner which travels out and in on the horizontal arm of a crane, so that the machine may command every point of the area swept by the latter.

Keels are sometimes machine riveted, for, as already noticed, large hand-closed rivets are always of doubtful soundness, whereas, when closed by hydraulic power, all rivets, whether large or small, are absolutely sound and reliable. To hydraulic-rivet a bar keel requires a special machine, and it involves the laying under the vessel's bottom of a temporary line of rails for the trolly which carries the riveter, long lengths of piping, and the consecutive removal of all the keel blocks—which, however, must be removed, in any case, at some period, for the caulking of the lower edges of the garboard strakes. Nevertheless, in view of the great efficiency of the work, and of the circumstance that the cost of keel riveting, when done by hand, is four or five times that of ordinary riveting, machine riveting may still be advantageous economically. In some cases the floors and intercostals of a double bottom are riveted together and to the vertical keel by hydraulic machines, which for this purpose are usually transported on rails laid on the tops of the floors. In the largest modern vessels, in which the riveting work may be very heavy, it is now not uncommon to machine rivet the sheer strake, and in some cases the strake below, and the deck stringer plates, which has the valuable effect of ensuring sound and reliable work, however large the rivets. In the yard of Messrs. Harland and Wolff (where only the largest class of vessel is built) a most extensive and elaborate hydraulic installation is provided, which permits of much of the hull being machine riveted in place. Here the machines are suspended from a travelling *gantry*, an enormous structure, about 100 feet high and the same in width, which bestrides the hull and travels fore-and-aft on permanent lines of rails.[1] These gantrys not only serve for riveting purposes, but for lifting and putting together the various parts of the structure.

Hydraulic riveting machines vary in design according to the particular make and the nature of the work they are intended to execute. Sketches of a representative machine are given in Figs. 16 and 17, Plate 115. Portable machines were first used about 1871, but since then numerous mechanical refinements have been introduced, such as hydraulic elevating mechanism and tilting gear, which, by giving a maximum of ease in moving and adjusting the otherwise cumbrous mass, secures the expedition and economy in working which are so essential towards their advantageous employment. Some are arranged with a double power, so that when closing small rivets a suitably small pressure may be brought to bear, thus avoiding useless expenditure of pumping power at the accumulator. Machines for heavy work are sometimes arranged with a sleeve round the snap die, which nips the joint in advance, and holds the parts

[1] Described and illustrated in *Engineering* for January 29, 1898.

together during the closing of the rivet; as already noticed, perfect preliminary contact of the faying surfaces is very important in machine riveting. Riveting machines are not all worked by hydraulic power; in some, compressed air is used, and in others steam; and they may do their work by steady pressure, as in an hydraulic machine, or by percussion, as in hand work. **Air pressure, or pneumatic, machines** are advantageous in some respects, but those usually employed have the disadvantage of giving a pressure which varies with the length of the rivet; for as the air pressure is only about 70 pounds per square inch, the necessary intense pressure on the rivet head is usually secured by working the die with a toggle joint, a mechanism which exerts an effort more or less intense according as its range of movement is great or small; with hydraulic power the die exerts the same pressure at all points of its stroke. An improved pneumatic machine[1] is now obtainable in which a sort of lever cam takes the place of the toggle joint, and thus secures more uniform pressure. **Air percussion machines** are advantageous in that they are very much lighter than those which operate by pressure; but as their action is simply that of a hammer (giving very short, rapid strokes), they are no more efficient in making sound rivets than are ordinary hand hammers, and, owing to their short stroke, their capabilities in closing the work are very poor. Machines of this type are much used in some of the North-American shipyards, but in this country they have, as yet, found little favour.[2]

Art. 319. Although steel has almost entirely superseded iron for the hull, it has not yet done so for the rivets, for the greater number of steel vessels are still riveted with **iron rivets.** **Steel rivets** are preferable in that they are tougher, more ductile, and stronger; they are exclusively used in Government dockyards, and also in many private yards; an exception, however, is usually made of the large rivets used for keels, etc., where, for ease in manipulation, soft iron is preferable. Formerly, steel was regarded as an unsuitable material for rivets, due principally to the circumstance that it was attempted to work steel rivets at the same high temperature as those of iron, a treatment which they could not well stand. Both steel and iron are injured by overheating; they burn, and emit showers of sparks; but in the case of iron, long before the burning temperature is attained it assumes the plastic condition suitable for welding or for easy manipulation under the hammer; and even if it should be overheated and burn, it is not so seriously injured that it cannot be worked. With steel, on the other hand, the plastic or welding temperature is little removed from the burning point, and, in burning, it suffers more than iron, a small mass such as a rivet being so injured as to crack and crumble under the hammer. The softer the steel, the further removed the burning temperature from the plastic, and so the less likely is it to be injured by overheating; and no doubt much of the difficulty experienced with the early steel rivets was due to lack of mildness in the steel. Steel rivets are now used with the most satisfactory results; the one point to be observed in their manipulation is not to heat them beyond a bright yellow; iron rivets are often raised almost to a white heat. The circumstance that iron rivets when slightly burned are not so injured that they cannot be worked is not a point in their favour, for such rivets are brittle and unreliable. The principle reason for the continued use of iron rivets is the greater ease with which they may be hammered up. Steel rivets are tougher, a drawback which is emphasized by the lower temperature at which they are worked; to close

[1] Fielding's patent.

[2] A description of these machines will be found in a paper by Mr. W. T. Babcock, *Trans. Institution of Naval Architects*, 1899.

them is more laborious, and, consequently, piecework riveters demand higher remuneration when using them.

The iron used for rivets is a high-class material; it has none of the brittleness of common plate iron, but is almost as ductile as steel. As already seen, its tensile strength is about 24 tons per square inch, but its shearing strength, when connecting steel plates, is low, being only about $16\frac{1}{2}$ tons. Steel rivets vary greatly in strength, but with a comparatively soft steel of 28 tons tensile strength a shearing strength of at least 23 tons per square inch is probable. Steel rivets are, therefore, about 40 per cent. stronger than those of iron, which, of course, is a very important advantage. The greater toughness of steel rivets may be observed when cutting them out in repair work, for while the head of an ordinary iron rivet will often fly off when struck one or two blows with a chisel and sledge hammer, that of a steel rivet may require to be almost cut off. Iron rivets, however, vary much, for when of good quality they are as tough to the chisel as those of steel. They are often defective in having an open reedy grain, which causes the head and shank to split during the hammering up.

It may be mentioned here that in repair work the removal of countersunk rivets whose heads, owing to inaccessibility, cannot be struck off with a sledge hammer and chisel, is accomplished by drilling a hole almost through the point (see Fig. 4, Plate 52) and then punching the rivet shank inwards; unless electric or pneumatic drills are available, such work is, of course, slow and laborious. The removal of keel, stem, and stern-frame rivets is accomplished by striking them alternately on the head and point with a sledge hammer, which causes the shank, after a few blows, to break across at the neck of the countersink.

Art. 320. Lloyd's requirements for the steel bars used for boiler rivets are a tensile strength of 26 to 30 tons per square inch, and an elongation under test of not less than 20 per cent. in a length of 8 inches; and the same class of material is generally employed for ship rivets. The Admiralty **tests for steel** bars for ordinary **rivets** is a tensile strength of 26 to 30 tons per square inch and 25 per cent. elongation, and for boiler rivets 24 to 27 tons with 25 per cent. elongation. Steel rivets and rivet bars are also subjected to various ductility tests (see Figs. 28 to 34, Plate 49), the most important of which is the staving up, mushroom-fashion, of the end of the bar or the head of the rivet (Fig. 31); whether hot or cold it should flatten out as thin as a sixpence without cracking around the edge; if flattened hot, the head may attain a diameter more than three times that of the shank. Another standard test is to bend the bar double, squeezing the two parts quite close together (Fig. 32). Whether the steel has a high or a low tensile strength, *i.e.* whether it be at the upper limit of 30 tons or at the lower one of 26, there is usually little appreciable difference in its behaviour under these tests; and in view of this, and of the advantage of strong rivets, it is evidently well and proper to employ a fairly strong steel. In some cases steel rivets are made from an exceedingly mild material, little stronger than good iron.

The **use of steel rivets** for shipwork is so limited that **Lloyd's rules** assume all to be of iron; to make special rules appropriate to the greater strength of steel rivets would not be expedient, for it would be difficult to ensure that all the rivets actually used are of steel, and that they have the high shearing strength anticipated. The rules of the **Bureau Veritas** state that if steel rivets, having a tensile strength exceeding 22 tons, are used, a suitable reduction may be permitted in their diameter. The rules of the **British Corporation** recommend the use of steel rivets. The general scheme of riveting adopted by the **Admiralty** differs considerably

from Merchant practice. Only steel rivets are used. There are no fixed rules as to sizes of rivets and the number in the joints; these matters are based on theoretical requirements as to equality of plate and rivet strength, computations being made for each important joint and the rivets arranged accordingly. As warships are not subject to the same intense structural stresses as merchant vessels, and as the plates are comparatively thin, the riveting is usually much less extensive; the shell joints are usually butted, and even in the largest battle-ship are not usually more than double riveted; and the rivet pitch is wider than that adopted in merchant vessels. As a rule the countersink is not extended quite through the plate. Buttstraps are rather narrower, and are not specially thickened.

CHAPTER XXII.

Art. 321. Caulking is not essential to watertightness, for, as noticed in Art. 295, if the rivets are placed sufficiently close together they alone may secure watertight contact between the faying surfaces; the workmanship, however, as regards the fitting and riveting, would have to be very perfect, and the faying surfaces quite smooth, conditions not always assured. The effect of the caulking tool, in the case of a lap joint, is shown in exaggerated form in Fig. 2, Plate 54; by staving up or thickening the edge of one plate, it forces it into contact with the surface of the other. Caulking tends to injure a joint, for, as shown in Fig. 2, the *shoulder* produced by the tool, while securing the desired contact at the edge, tends to force the two parts asunder elsewhere.

Caulking tools are illustrated in Fig. 9, Plate 54. In caulking a seam, a "splitting" tool (A, Fig. 9) is used first in the manner indicated in Fig. 10, so as to make a small furrow in the edge of the plate. Then a second, or "setting-in" tool (which is practically the first reversed), is employed, which completes the work by making a square groove (Fig. 11), from $\frac{1}{8}$ to $\frac{3}{16}$ inch broad, the material displaced forming the projecting bearing shoulder, which is held by the natural spring or elasticity of the plate in tight contact with the surface of the other. In yards on the north-east coast of England a third, or "finishing" tool, is employed; this is simply an extra fine caulking tool, and is applied lightly to ensure perfect contact of the bearing surfaces; its use is unnecessary if the caulking edge has been smoothly planed. In a well-caulked joint the shoulder should be deep, as in Fig. 3, rather than high, as in Fig. 1, for a high shoulder, by separating the plates, destroys the frictional resistance of the joint, and is less substantial and enduring. To make a deep shoulder, a heavy hammer must be employed, for its greater momentum has a deeper staving or disturbing effect; a light hammer, although it may be used with greater energy, expends its effort on the surface, raising a high but shallow shoulder. In boiler work the seams are sometimes caulked with a tool having a rounded edge (see Fig. 4).

In **caulking a butted joint** the effect produced is similar to that just described, but instead of the edge being thickened by staving, it is elongated by thinning (see Fig. 6, Plate 54). With closely butted joints little caulking is required; if wide and gaping, as in Fig. 6, a deep groove is necessary to produce the required elongation, and even then the contact is only on the surface; if the edges are too far apart, strips of iron are first introduced and hammered down with the caulking tool, a practice the objectionable features of which are noticed in Art. 297. It is not so easy to caulk a butted joint as a lapped one, for there is nothing to guide the tool, and for this reason piecework caulkers demand higher remuneration for the work. The watertightness of a butted joint depends greatly on the caulking, for even when carefully planed and fitted the ends of the two plates rarely meet with perfect watertight contact at every point. In the

early days of iron shipbuilding plate-edge planing machines were hardly thought of; to make tightly fitting joints the ends of the plates were sheared rather full, and were then staved up by numerous hammer blows so that they might fit properly against one another. In the staving process a projecting ridge was formed, which was regarded as an advantage, for after the plates were riveted together watertightness was at once secured by hammering the ridge into the joint, flush with the plate surface. This procedure appears now to be barbarous in the extreme, especially with iron plates, brittle, laminated, and readily split; the effect of corrosion in such joints, owing to the disintegration caused by the hammering, must have been rapid and destructive.

In ordinary **caulking** work light **hammers** are employed; where the plates are very thick, heavier ones may be advantageously used. Sometimes in large vessels the joints of the shell plating are "*horsed*"; *i.e.* two workmen operate together, the one holding the caulking tool (which is provided with a loosely attached handle) and the other striking it with a long-shafted hammer; but with good fitting and riveting work this method of caulking is likely to be injurious rather than beneficial, for it may force the faying surfaces apart, and not be uniform in its effect. Many of the seams are so disposed that, in caulking them, the hammer must be held in the left hand; the lapped shell joints on the starboard side, for instance, require a left-hand caulk. Not all caulkers are skilled with the left hand, and so it is well, in arranging the internal work, so to dispose the seams as to avoid left-hand caulking; in the transverse bulkheads, for instance, the horizontal caulking edges should face upwards, and if caulked on the forward surface the vertical edges should face to port.

Caulking work requires conscientious care; as a rule it is well done, and if not, the fault is usually in the fitting and riveting, the joints not being properly closed in the first instance. The perfection of the work is **tested** by the general appearance of the groove formed by the tool, its width and depth, and by applying the point of a thin knife; in dark places, such as the bottom seams of the shell plating, the inspection is assisted by a small mirror, held so as to reflect the seam or to throw upon it a beam of light. The groove should be from $\frac{1}{8}$ to $\frac{3}{16}$ inch wide, according to the thickness of the plate; a narrow groove implies a shallow caulk. If a joint is not closely riveted, as is sometimes the case with the edges of the bilge strakes (see Fig. 8, Plate 54), a large amount of staving effort, with its result, a deep groove, is required to raise the necessary bearing shoulder. If closely fitted, very little bearing shoulder is required, and so the groove may be shallow. The depth of the groove is, therefore, no criterion of the perfection of the caulking, for although a deep one may apparently denote a solid, conscientious caulk, a shallow one, if the joint is riveted perfectly close, may really be the superior, indicating a well-riveted joint. Sometimes, in careless work, the caulking tool is held so improperly as to raise a furrow in the surface of the other plate (see Fig. 5).

Art. 322. Some excellent **pneumatic caulking tools** are now available, but as yet they are not extensively used in the shipyard.[1] They are worked by compressed air, and deliver short-stroke blows with vibratory rapidity. In operation they are held in the hand, and require merely to be guided along the seam, the tool indenting a deep groove with great rapidity. They have been proved very suitable for straightforward work, such as the shell, decks, and tank top, but the inconvenience of the tubing necessary to convey the pressure air makes them awkward to use for odd

[1] A description of one of these machines will be found in Mr. MacEwan Ross's paper, *Trans. Institution of Engineers and Shipbuilders in Scotland*, 1893.

jobs. The same machine may be adapted for chipping purposes; when a chisel is substituted for the caulking tool, it can chip the edge of a plate or the point of a rivet with remarkable expedition. Pneumatic caulking, chipping, and riveting tools, or hammers, are now extensively used in some of the shipyards in the United States of America.

Art. 323. The **caulking edges** of the shell plating are **smoothly planed**, and if, before caulking, there is any apparent unfairness, it is corrected by chipping. Other plating, if it is thin, is often not planed before caulking. A shearing machine, when in good order, can cut the edge of a thin plate so smoothly and squarely that a close scrutiny may be necessary to ascertain whether or not it has been planed. But, of course, according to the way a planing machine is worked, it may make a smooth or a very rough cut; if so rough that it resembles a sheared edge, the planing is of little value. With ordinary shears and thick plates, the knife tends to round over the upper edge, leaving the lower one sharp and square or raising a small *burr*, *rag*, or *fin*, as shown in Fig. 7, Plate 54. When it is not intended to plane the edge of a plate, it should be so shorn that the sharp edge may be *against* the other plate (see A, Fig. 7), for then the faying surfaces of the joint will be in close contact right up to the edge, and when this is well hammered during the riveting it will be almost watertight without caulking; the effect, when disposed contrariwise, is shown at B, Fig. 7. Although a sheared edge may be tightly caulked, the work is inferior to what it is when it is smoothly planed or chipped (in some yards the deck, tank-top and bulkhead plates are neither planed nor chipped before caulking), for when in the latter condition a minimum of staving will produce uniform contact; with a rough, sheared edge (as also with a roughly planed one) little particles of metal from the ragged edge are apt to be driven into the seam by the caulking tool, so that the caulking is less perfect and more care is required to secure watertightness, a circumstance which piecework caulkers observe by demanding higher remuneration for the work.

The **toes of an angle bar**, being slightly rounded, should be **planed or chipped before caulking** (see the watertight reverse bar in Fig. 12, Plate 54). In many cases, however, watertight bars are caulked without any preliminary planing or chipping, but this is not good practice. Small odd bars are usually chipped when riveted in place, as a prelude to the caulking; long bars, however, are usually planed. Straight bars may be planed in an ordinary plate-edge planing machine; if curved they may be planed before bending, but if the curvature or bevelling is extensive, and involves furnacing (as in bulkhead frame angles), the work might injure the planed edge, and in such cases, therefore, hand chipping, in place, is usually resorted to. An ordinary planing machine is not very suitable even for straight bars, for as these are never perfectly straight, the tool must be guided to ensure an even cut. Special planing machines are now made for this work (Fig. 18, Plate 115); when in operation the bar is drawn between rollers, while fixed cutters, one for each flange, plane simultaneously the edges of both.

Art. 324. The caulking of a straight seam is a simple matter; but in the case of **smithed angle bars**, such as watertight collar angles and the watertight divisions of a double bottom, it is not so easy. In collar angles, for instance, such as those shown in Figs. 3 to 10, Plate 55, it is practically impossible to fit them with precision at all the corners of the parts surrounded; the riveting cannot, as in a seam, produce contact at every point, and so chips or wedges of iron must be driven into the crevices as a preliminary to the caulking. To make all tight requires a skilful use of the caulking tool;

there is no well-formed groove to guide it, and in places it has to be applied over a wide area. For such work a tool (B, Fig. 9, Plate 54) having a serrated edge (made by striking it while hot on a file) is used, for when a smooth one is applied to an irregular surface it is apt to skid and jar the hand of the operator. This tool is also used for caulking butted joints, hence the term "*butt tool.*" It is sometimes employed for ordinary edge caulking, but its use here is improper, for while, by more quickly indenting a groove, it expedites the work, it tends to break up and damage the steel.

Art. 325. Riveted joints may, when necessary, be made watertight without caulking, by placing soft, oily material between the faying surfaces. The most durable **soft packing** consists of strips of woven *flannel* dipped in redlead; *felt* sheeting, however, is the material generally employed, and sometimes simple **putty or Vulcan cement** (the latter is merely a cheap form of putty, the consistency of which may be regulated in the same way, by the addition of oil). The use of soft packing is—or should be—confined to joints which cannot be properly caulked; or as an auxiliary to the caulking, in places where, through intricacies in the work or inaccessibility, the caulking, being difficult to perform, is not entirely reliable; it is commonly used, for instance, for watertight collar angles, tank divisions, margin-plate lugs, etc.

A joint that owes its watertightness to soft packing is inferior to one that is riveted metal to metal and caulked; for, with soft, oily material between the faying surfaces, the rigidity of the union must be inferior, there can be little frictional resistance, and with the lapse of time there is a chance of the soft material decomposing, losing its water-excluding properties, and destroying the solidity of the joint. The interstices of a **metal-to-metal joint** become, in course of time, hermetically sealed by a hard, cohesive film, or scale of rust, which increases the frictional resistance and solidity of the joint, and secures watertightness independently of the caulking. Few vessels when launched are absolutely watertight at every joint and rivet, but in a very short time the formation of rust within the minute crevices forming the leaks proves a perfect remedy. And, similarly, in old vessels many of the seams do not owe their watertightness to the caulking, for the edges of the plates may be worn away beyond the caulking, and yet be perfectly tight. When oily packing is introduced between the faying surfaces, it prevents the formation of rust, with its valuable solidifying and tightening effect. For this reason, in high-class work, its use is very limited. The classification societies specify metal-to-metal joints.

Art. 326. In many places soft packing, in the form of a "**stop-water,**" is essential to watertightness. The purpose of a stop-water may be illustrated by considering the case of, say, a deep-tank bulkhead. Although the bulkhead itself may be perfectly watertight, it is evident that each shell landing, traversing it, may form a conduit for the water, for, as this is free to enter between the faying surfaces of the landing, it may travel fore and aft and escape at any point of the uncaulked edge. If both edges of the landing were caulked, it would form a sort of flattened pipe into which water could neither enter nor escape; but, of course, to caulk the inner edge of the shell landings all fore-and-aft would be impracticable. The simple plan is, therefore, adopted of choking up the landing where it traverses the bulkhead, by a stop-water of felt and redlead. Stop-waters must be inserted at every place where two conjoined thicknesses traverse a watertight surface; at the watertight bulkheads they are required between the different angles of the keelsons and side stringers, and in the landings of the shell, deck plating, and tank top; also, between the angles of the vertical keel in way of tank divisions; and between the frames, reverse

bars, and shell where carried through tank top plating. And it is well to fit stop-waters between the frame, reverse bar, and shell in way of decks which may be flooded with water (Fig. 1, Plate 19).

Care must be observed that at no places are the necessary stop-waters omitted, otherwise considerable difficulty may be experienced in closing the conduits left open by their absence; caulking is then of little use, for if water once passes between the faying surfaces, it may travel along and emerge far from the source. The expedient then adopted is to introduce a stop-water in the form of thick redlead or thin putty, by means of an **injector** (see Fig. 1, Plate 54). In its simplest form, this consists of a cylinder having a screwed nozzle and a long screwed ram or plunger (with or without a cup-leather). When using it, a hole is drilled and tapped through one of the thicknesses forming the conduit or leak, the nozzle of the injector is screwed tightly into this hole, and the thin putty contained in the cylinder is then injected between the faying surfaces, by screwing down the plunger. So great is the power of this contrivance that the putty will penetrate into all communicating crevices, spreading between the faying surfaces, however well closed, a circumstance shown by its exuding from the seams or rivet heads, perhaps some feet away from the source.

Art. 327. In watertight work three-ply rivets are usually regarded as objectionable. But the watertightness of a rivet, as a plug, is not affected by the number of thicknesses it passes through, so long as its head or point bears directly on the particular surface which is the caulked and watertight one. If, on the contrary, the watertight surface is a *central* thickness, its tightness at each rivet is not always assured, for although the point, head, or neck of the rivet may plug tightly the two exterior thicknesses, the shank, remote from either the point or head, is not so certain to plug tightly the hole in the central watertight thickness. This is illustrated in Fig. 12, Plate 54, which represents a rivet passing through the tank-top plating, a reverse bar below, and a pillar lug above; the rivet is defective, and the water leaking from the tank is shown by the arrows. A similarly defective three-ply rivet is shown in Fig. 13, but as the middle thickness is not here the watertight one, the rivet may be perfectly tight. In a small part like a pillar lug, leakage due to a defective rivet may be corrected by caulking all around it, otherwise the precautionary measure may be taken of interposing a strip of felt between the lug and the tank top. And similarly with other bars riveted to the tank top and margin plate (such as those for the engine seating, boiler stools, and tank-margin brackets), but as it may be impracticable to caulk all around these parts, soft packing is generally introduced. Sometimes, instead of felt, rope yarn, with or without putty, is looped around the rivet holes (or a small ring of rope-yarn—a *gromet*—may be introduced at each one), the possible source of leakage; but although this method ensures watertightness, it is very objectionable, because the irregularly distributed rope-yarn entirely precludes uniform contact of the faying surfaces.

In watertight work, where three thicknesses come together, it is always sought to avoid such disposition as will make the watertight thickness the *central one*, for, as just seen, the watertightness of the resulting three-ply rivets is not then assured—*i.e.* without special precautions. The intercostal plates, for instance, in a double bottom are usually connected, one on either side of each floor plate, by the same three-ply rivets (see A, Fig. 14, Plate 54); but when they abut on a watertight floor the connecting angles should be reversed in order to avoid three-ply rivets (see B, Fig. 14). Until recently the floor plates within the tank and the frame brackets without were connected to the tank-margin plate by different rivets,

the connecting angles (when single) being reversed, as at A, Fig. 7, Plate 17. But the classification societies now require the angles to be placed opposite each other, as at B, which involves three-ply rivets. The objection to these, however, is one that can be overcome by careful workmanship, with or without the judicious use of soft packing, and, as noticed in Art. 192, the structural strength is superior when the two severed parts have a direct through attachment. As a rule, however, it is preferred to reverse the angles, and, as compensation for the inferior holding effect, fit the outer one with an extra large flange, as shown at C. It is chiefly in tanks whose constant duty it is to retain water, and which must withstand a pressure test, that special care is taken to avoid such three-ply rivets as would necessitate soft packing. Ordinary bulkheads, which may never be called upon to withhold water, usually receive less attention. In **oil vessels** particular care is taken to avoid three-ply rivets, for, of course, greasy packing material is inapplicable as a leak-stopper for paraffin oil. To secure oil-tightness, therefore, the most perfect workmanship is essential, the parts must be accurately fitted, the rivets closely spaced, and all holes made perfectly fair so as to ensure their being properly plugged by the rivet shanks.

Art. 328. In **caulking** a watertight surface such as a bulkhead, it should be done entirely **from one side**; if partly on one and partly on the other, there is no termination for the caulk, and, in the absence of soft packing, perfect watertightness is impossible. In properly executed work the furrows formed by the caulking tool should have no termination; they should abut on others and form, as it were, continuous loops; if at any point the caulking stopped short, the water would (unless stop-waters were introduced) be free to enter between the faying surfaces or edges of the plates, pass along and escape. With double bulkhead frame angles, only one of them is caulked (in the case of the bulkheads of deep tanks both angles are often caulked), usually the after one in the case of the forward bulkheads, for, owing to its open bevel, it is more accessible: and, of course, the remainder of the bulkhead should be caulked from this side. When a part is to be caulked, care must be taken that the edges are everywhere accessible to the caulking tool; the ends of the bulkhead stiffeners, for instance, should be cut about an inch short of the boundary angles, etc., and, similarly, in the case of the tank margin angle, the frames, etc., should be cut clear of its toes (see Fig. 18, Plate 17). Particular care is always taken to secure watertightness in the collision, after-peak, and deep-tank bulkheads, for the work has to be tested and defects made good; a thick layer of putty is usually placed over the open crevice between the double frame angles, which becomes squeezed out by the riveting and forms a good stop-water. With a bar keel the triangular spaces between the garboard plates and its upper edge are usually filled by driving in wedges of iron, watertightness being ensured by a good body of cement.

Where continuous parts, such as the keelsons, stringers, and frames, pierce watertight plating, such as the bulkheads and tank top, they must be surrounded by **smithed angle bars**, termed "*collars*" (see Figs. 3 to 14, Plate 55). These are made by workmen known as "*angle smiths*," who make the necessary templates and fit the collars ready for riveting. Their design varies according to the shape and position of the part surrounded, it being studied to simplify and minimize the fitting, caulking, and riveting work.

Art. 329. Sometimes, when a large number of **collars** of identical form are required, as where beams pierce longitudinal bulkheads or

casings, they are made **of cast steel or malleable cast iron**, in bulk, from a single pattern; and knee pieces, such as are used at the corners of fresh-water tanks (Fig. 15, Plate 55), are very commonly made of cast steel. Watertight collars must, of course, fit closely around the part, but the hole in the watertight plating may be large, so that the part may be easily reeved through (Figs. 11 to 14); and it is usual in such cases to place on the side opposite to the collar angle a well-fitted plate, or "plate collar," which serves to cover up the large hole, to stiffen the thin plating against the bursting effect of the caulking, and to retain the putty usually inserted behind the collar angle (Fig. 13). Sometimes carelessness is displayed in the collaring of deck-stringer plates, etc., where they pierce watertight bulkheads; the collars should, of course, entirely surround the stringer and gunwale bar, and be all on the one side of the bulkhead, as shown in Figs. 5 and 7, Plate 22, or Fig. 11, Plate 55.

Art. 330. A caulked watertight surface is equally tight whether the **water presses on the caulked or on the uncaulked side**; in the latter case the water is free to enter between the faying surfaces of the joints, a favourable circumstance, in that the rapid formation of rust within the joints conduces to watertightness irrespective of the caulking, but unfavourable, in that, entering freely between the faying surfaces, it may tend, if excessive, to spring them apart, start the caulking, and strain the rivet heads or points. As regards the securing of watertightness in new vessels, it is very advantageous that the caulking side should be open to inspection when the bulkheads and tanks are tested by water pressure. A deep-tank bulkhead, for instance, is always caulked on the surface external to the tanks, so that, when tested by filling the tank with water, any defects are at once observed and may be corrected forthwith; if it were caulked on the inner surface, then, as leakage water might travel along the joints and ooze out extensively by the uncaulked edges, it would give no precise indication of the nature and position of the leak within, whether due to defective caulking or rivets. As the leak could not be properly corrected from the outside, the tank would have to be emptied, the defect searched for and made good as far as practicable, and the bulkhead retested. Each tank of the double bottom is separately tested, and, as it is at its watertight ends that defective workmanship and leakage are most likely to occur, these parts must be examined during the test; and, to permit of defects being readily made good, care should be observed that the caulking is not on the water side during the test. In many cases the precautionary measure is taken of caulking both sides of watertight divisions, the heel of the bar on the one side, and the toes on the other; and in the case of deep-tank bulkheads both of the double marginal angles are usually caulked, and stop-waters inserted at every landing between them. If, in Fig. 12, Plate 54, the heel of the reverse bar were caulked, water could not pass from one tank to the other *viâ* the defective rivet. If, on testing a tank, leaky rivets which cannot be corrected by caulking are discovered, they should, of course, be renewed, and not with studs screwed in from the outside. This involves emptying the tank, and it is desirable that it should be again filled and retested, otherwise it would be uncertain that the defects —unless of a simple nature—had been properly remedied, or that the performance of the work had not disturbed the watertightness of contiguous parts.

Art. 331. The masts and yards are not generally caulked; the masts should be, for a few feet above the deck, so that, in the interval of time before a rust-tight joint is formed, water may not freely enter the seams and pass down into the hold. In high-class work all spars are caulked,

this being advantageous in preventing water from entering the joints and causing corrosion, the effects of which are noticed in Art. 466. And, for a similar reason, all joints of thin plating, etc., exposed to the weather on deck should be caulked. The shaft tunnel is, of course, carefully caulked, and the classification societies require that in new ships it shall be tested with water, this being done usually by hose from the outside. Particular care must be observed in securing watertightness of the upper-deck gunwale bar, where the buttstraps of the sheer strake or the chain plates for the shrouds may overlap it (Art. 167). Lloyd's rules require the watertightness of the upper deck to be tested by playing water upon it from a hose, and where there is a gutter waterway it should be tested before cementing; sometimes this is done by forming a trough with deals, about a foot deep, and filling it with water. These precautions are very necessary, for in new ships valuable cargo has sometimes been damaged by deck leakage, through undiscovered defective joints or rivets.

Art. 332. The **ballast tanks** of all new vessels are **tested** by filling them with water, and, in the case of old vessels, the classification societies require periodical tests, at least every four years. In new vessels the tanks are rarely found perfectly tight on the first test; the shell portion generally is, for the fitting, caulking, and riveting work is here a simple affair; but in the case of the tank top, sides, and ends, the work is not so easy, and, consequently, some of the three-ply riveting, or the caulking in awkward places, is often defective. In old ships periodical tests are useful in assuring that no leakiness or other defect has developed through wear and tear, for as the structure of a tank is discontinuous and comparatively slender, its endurance of stress is not equal to that of the shell. In these tests it is not uncommon to find the tanks more or less leaky. If extensive leakage were to occur when the vessel was at sea, the consequences might, of course, be serious, for before those on board became aware of the circumstance, the water, passing from the tank into the hold, might damage valuable cargo. Of course, if a vessel's tanks are constantly used, their condition, whether tight or leaky, is practically under constant test, but sometimes they may not be used for long periods, or they may not be filled sufficiently to cause pressure and bring defects to light.

As the **water pressure** endured by a tank depends on the vessel's draught, the pressure applied in testing is also regulated by this quantity. Water, like all fluids, presses equally in all directions. A submerged surface, however disposed, suffers a pressure equal to the weight of a column of water whose height is the depth of submergence (measured to the centre of gravity of the surface), and whose cross section has an area equal to that of the surface. It follows, therefore, that the bottom plating of a vessel whose load draught is, say, 18 feet, is subjected to an upward pressure of about half a ton per square foot (for 36 cubic feet of fresh water weigh one ton). If, now, in this vessel, the double bottom were full of water, and a valve in the shell plating were opened, all pressure would at once be transferred to the tank top; the shell, being submerged, would suffer pressure as before, but being now pressed equally on both sides, it would be in equilibrium, and—neglecting its weight—might be removed without affecting the vessel's flotation. The vessel would then float on her tank top, which, if 18 feet below the surface, would sustain a pressure of half a ton per square foot. This is the maximum pressure which the tank would suffer, and, therefore, it is the pressure that should be applied in testing it. When a tank is tested afloat it is usually done in this simple way—by opening the flooding valve so that the sea may freely enter. If the vessel were floating at light draught, say 9 feet in place of 18, then, of

course, the pressure of water on the tank top would only be one-half as great. Lloyd's rules require the tanks of new vessels to be tested by a water pressure equal to that which occurs at *load draught*, but in the periodical tests of old vessels by only that due to the *light draught*. The rules of the British Corporation require the load draught pressure in all cases. It should be observed that, in actual service, when a vessel uses her ballast tank she is usually in light trim.

When a vessel's tanks are tested in dry dock, or before launching, the test pressure is obtained by filling the tanks by hose, so full that the water rises in the sounding and air pipes (or in a vertical stand-pipe fitted temporarily for testing purposes) to the height of the light or load line. The pressure brought to bear on the inner walls of a tank is then precisely what it would be if the vessel were afloat with a valve in the shell plating open, in either case the head of water, causing the pressure, being equal to the vessel's draught.

As a rule, foremen and others, whose duty it is to superintend tank-testing operations, have little conception of the **principle of hydrostatic pressure**. Its visible effects are appreciated, but precisely how they are brought about is not understood. It is found difficult to conceive that the mere filling of a vertical stand-pipe, say 18 feet high and 1 square inch in sectional area, and holding about a gallon of water, should at once impose, on every square foot of the tank walls, a bursting pressure of half a ton, or a total pressure on the whole of the tank top of many hundreds of tons. That it does so is readily seen by the circumstance that, as the water rises in the pipe, the tank-top plating often begins to bulge perceptibly upwards between the floors, and joints, formerly tight, begin to leak. This fundamental law of fluid pressure may be simply illustrated by the following experiment: Imagine a second stand-pipe, of 1 square inch sectional area, to be erected anywhere else on the tank top. As there are now two pipes, the water in the first, finding its own level, will sink to half height, and in the other rise to half height (the walls of the tank are assumed to be perfectly rigid). If now the water in the second pipe be forced down into the tank by, say, a piston, it will rise again to the top of the first. To keep it at this height will require a pressure on the piston (the piston, being now in the plane of the tank top, may be regarded as a square inch of tank top plating) equal to the weight of water in the pipe; evidently, for if the first pipe, now full of water, were plugged up at the bottom, the plug would support the weight of the water lying above it, and as no downward pressure would now be required of the piston, that of which it is relieved is that taken by the plug, namely, the weight of the water in the 18-foot stand-pipe. Similarly, every other square inch of the tank top (which may be regarded as composed of numerous pistons) is subjected simultaneously to a pressure equal to the weight of the column of water in the single 18-foot stand pipe.

In some vessels the ballast tanks may be filled by forcing water into them through the steam ballast pump. In such cases, as the water, when the tank is quite full, rises in the air pipes until it overflows on deck, the pressure brought to bear on the tank may be considerably greater than that due to the vessel's draught. In testing a tank, the pressure applied should evidently not be less than that which may be imposed in actual service, and in tanks, therefore, which are pumped up the test should be made with the water issuing from the air pipes. **Deep ballast tanks** are usually pumped up, for when the vessel is at light draught the crown of the tank may be above the sea-level, when, of course, the tank could not be filled by merely opening a valve. In the case of peak tanks, however, provision is

sometimes only made for filling them through an air pipe, by a hose from the deck. Lloyd's rules require deep tanks to be tested by a head of water 8 feet above the tank top.

The **oil tanks** of petroleum vessels are subjected to a **more severe test** than water-ballast tanks; Lloyd's rules specify a head of water 15 feet above the deck forming the crown of the tank. This, however, is not usually more than 9 feet above the normal surface of the oil in the expansion trunks, which usually lies about 6 feet above the crown of the tank (Fig. 11, Plate 26). The pressure due to a 15 feet head of water is about $6\frac{1}{2}$ pounds per square inch; but this is only what the crown of the tank suffers, the pressure affecting the bottom plating in a tank, say, 20 feet deep, would be 1 ton per square foot. When the vessel is afloat much of this pressure is, of course, counterbalanced by that of the sea, but not so the pressure on the transverse bulkheads, which in a bulkhead, say, 20 feet by 20 feet (the portion on one side of the centre line bulkhead) would amount to nearly 300 tons. To withstand so great a pressure without signs of straining or leakiness, it is evident that a large flat surface like a bulkhead must be very strongly constructed. It is proper that the tanks of oil vessels should be tested by a pressure somewhat higher than that which occurs in actual service, for oil is more searching than water, and so, when employing water as the testing fluid, the greater head compensates in a measure for its greater viscosity. Further, as the containing walls of a deep tank may be subjected to blows of a severely straining nature, and as the ordinary fluid pressure affecting them may be largely accentuated by the vessel's plunging movements (Art. 8), their capabilities are better ascertained by a high pressure test.

In the actual **work of testing tanks** there are several points to consider. It must first be ascertained that the tank is quite full of water; often it appears to be so, but, owing to insufficient or badly disposed air pipes, volumes of air may be imprisoned under the tank top, when, of course, should there be a small leak, as only air would escape therefrom, it might not be observed. Also, it must be ascertained that the water is at the required height in the air pipes, and that it remains so during the inspection. When filling a tank, whether through a flooding valve or hose, the water may at one moment fill the sounding pipe and the next subside and leave it empty; this, of course, is due to the irregular escape of air imprisoned in the tank.

The increase in the capacity of a tank under pressure, due to upward **bulging of the thin tank-top plating** between the floors and longitudinals, is often very considerable. It may be demonstrated in several ways: when filling a tank, for instance, it may be ascertained (by taking soundings) that it is quite full, and that the water in the sounding pipe is lying just above the level of the tank-top; now, if the walls of the tank were perfectly rigid, it is evident that about a gallon of water would be sufficient to fill the pipe to the top, and at once place the tank under test pressure; yet, actually, with the hose flowing full-bore into the pipe, it may take some minutes to fill it. This, of course, is explained by the fact that as the water rises in the pipe so does the pressure on the tank top increase; the plating, therefore, bulges upwards more and more, and thus increases the cubic capacity of the tank. Such bulging may be observed more or less in all tanks; in those built on the McIntyre system it is often very pronounced (Art. 186). Its effect in increasing the capacity of the tank may be strikingly illustrated by disconnecting the stand-pipe (at the tank top) when the tank is under pressure, a large quantity of water will then escape, rising in a jet and continuing to flow for a considerable time. On observing the tank top,

the various bulges will be found to disappear, the flexible plating resuming its normal form; and it is, of course, this subsidence, or bellows-like action of the plating, that causes the ejection of the water.

When a tank is filled for testing, soundings may be taken to ascertain the depth; if filled when afloat, through a valve, the latter should be left open during the test to ensure the continuance of the pressure. Sometimes a temporary stand-pipe is screwed into the tank top, and a small barrel fixed on the top to act as a reservoir and filler; otherwise, when the tank is filled by hose through a sounding pipe, the top of the stand-pipe may be bent over, so that a constant stream of water issuing therefrom (a barrel being provided for its reception) indicates that the proper head of water is maintained. Sometimes the stand-pipe is pierced with small holes about a foot apart, each one being plugged up, so that by withdrawing them from the top downwards the height of the water in the pipe may be ascertained at any time. The best method of testing the tanks of new vessels, and one very generally adopted, is to connect a hose to one of the drain plugs in the shell plating, and lead an escape pipe up from the tank top and overboard, through the side at the level of the load line, so that a constant stream of water issuing therefrom may announce that the tank is under pressure. The tank top and side gutters must, of course, he kept dry during the test, sawdust being used to absorb leakage water.

Art. 333. The **interior of a tank** is usually **cemented before the test,** the shell with a thick layer and the remainder with cement wash. This is not improper, for although thick cement on the shell might stop a leak, there is here little chance of leakage; in vessels not having a double bottom the shell is cemented before the launch, and there would be no reason for omitting it when there happened to be an inner bottom. The cement wash is so thin that it has practically no leak-stopping properties. As there is always a chance of leakiness in the angle bar connecting the tank margin plate to the shell, the cementing of the gutter at the side of the tank must be deferred until after the tank is tested. And so also should the cementing of the frame space on either side of the watertight divisions, and more particularly if the tank is to be used for fresh water for drinking purposes, for, of course, the smallest leakage of salt water into a fresh-water tank would be a serious matter. To ensure watertightness, a very improper use is sometimes made of cement; for, where confidence is not felt in the caulking of awkward corners, in way of smithed collars, etc., bad workmanship is sometimes provided against by introducing at these places, within the tank, thick masses of cement. And sometimes certain rivets in the margin plate, in which watertightness is difficult to secure, are covered over on the inside with a coating of thick redlead; but this, of course, is improper, for it might make an unsound, leaky rivet appear tight during the test.

Art. 334. There are many parts whose **watertightness** cannot be **tested by** solid water, and in such cases a **hose** may be employed. When carefully directed, a powerful jet of water will readily discover a leak, its effect when impinging with force on a joint being precisely that of still water under statical pressure; but, of course, on account of its momentary or transitory character, it is possible that a small leak might be passed over. The ordinary transverse bulkheads are sometimes tested by hose, and, as already seen, the classification societies require that the tunnel and the deck, whether plated or of wood, shall be so tested.

CHAPTER XXIII.

Art. 335. The **thickness of a wood deck**[1] varies with the general size of the vessel, with the character of the deck, and with the species of timber. Thickness is advantageous in giving strength and rigidity, so that when supporting heavy weights, or when struck by falling seas, the planks may not strain up or down between the beams relatively to one another, so as to start the caulking and cause leakiness; and in providing a margin against the thinning effect of wear and tear. The thicknesses specified in Lloyd's rules for pine upper decks vary from $2\frac{1}{2}$ inches in vessels less than 2800 plating numeral, to 4 inches in those over 15,100 plating numeral. It is evident that stiffer and stronger planks are required in large vessels, not only on account of the wider beam spacing, but because of the more intense stresses, local and otherwise, which accompany increase in size. Deck planks so thick as 4 inches are only found in the upper decks of sailing-ships, for in steamers of similar size the deck is usually plated. When teak is substituted for pine, Lloyd's rules permit of a reduction in thickness of one-sixth, on account of its greater strength and durability. A lower deck is usually thinner than an upper one by 15 or 25 per cent.; and if not required for structural purposes it may be laid in an incomplete fashion (see Plate 101). In the spar-deck type of vessel Lloyd's rules require both the upper and second decks to be $3\frac{1}{2}$ inches thick. In awning-deck vessels the second deck is regarded as the main deck, the awning deck above being 25 per cent. thinner; and this also applies to poop, bridge, or forecastle decks.

The thickness of **wood sheathing** must be such as will permit of substantial caulking and of the bolt heads being sunk so far below the surface that, when the deck is worn thin, they may still remain covered by the dowels; also, it must be such as will ensure freedom from warping tendencies in the planks. Lloyd's rules as to the thickness of pine sheathing is 3 inches for upper decks and $2\frac{1}{2}$ for lower; and for teak sheathing, $2\frac{1}{2}$ and 2 inches respectively.

Those deck planks which pass over tie plates, stringers, etc., are checked on the under side, and the joints, etc., of the plates should be so arranged that the check in the planks does not exceed one thickness of plating. Sometimes, instead of checking the planks, thin pieces of wood, or *pads*, are placed on the beams to bring them level with the plates; this is objectionable, however, for the pads are liable to decay and displacements; it is not allowed by the classification societies. In the case of wood sheathing the planks on the inner strakes are usually of the specified thickness, those on the outer being thinner by the thickness of the plating.

The usual **breadth of deck planks** is 5 inches, for although to make them wider would reduce workmanship, they would be more liable to

[1] In the following, the terms "wood deck" and "wood sheathing" will be used distinctively.

warp and split, and would be more likely to contain original defects. When they are 4 inches thick, as in sailing-ships, their breadth also is sometimes made 4 inches, for there is then a choice, when laying them, of placing any one of the four sides uppermost, and thus ensuring a sound upper surface, free from knots and shakes. Narrow planks give a deck a nice appearance, and for this reason 3-inch planks are commonly employed in yachts, and sometimes for the promenade decks of passenger vessels.

Art. 336. In wood ships the deck is a part of considerable structural importance, for the planks act in concert with those of the side in maintaining the longitudinal form of the hull. In a planked surface the butts are, of course, points of weakness, and in order, therefore, to minimize their prejudicial effect on the strength of the whole, care should be observed to distribute them as remotely as possible from one another. Lloyd's rule for the **shift of butts in the deck planks** of wood ships is the same as that for the planking of the sides and bottom, namely, that between butts falling on the same beam, or frame, there shall pass at least three intact planks (Fig. 18, Plate 56); that butts in contiguous planks shall be at least 5 feet apart, and those in alternate planks 4 feet apart. With the long pine planks available for decks, a better shift of the butts is usually obtainable, but, nevertheless, on account of the wide spacing of the deck beams, compared with the frames, this does not necessarily imply a better distribution of their weakening effect, for, of course, the mere lengthening of a scarph joint does not improve its strength against tensile stress unless there is an increase in the connecting medium. In steel vessels the strength of the structure, as a whole, is little affected by discontinuities in the deck planking, but as a wide distribution of the butts is readily obtained, it should be made. As regards the rigidity of the deck surface, the butts form points of weakness; it is common, for instance, for those lying near the corners of a 'midship deck house to become defective and leaky, through local straining of the deck, due to the rigidity and weight of the deck house. To stiffen and strengthen the deck at these places, the excellent plan is often adopted of laying a broad plank of teak wood all fore and aft alongside the deck houses and hatchways.

Art. 337. There are practically only four **kinds of timber** used for decks: yellow pine, pitch pine, Oregon pine, and teak. **Teak** is the best, but it costs about twice as much as pine, due in great measure to the fact that in converting the log into deck planks a large quantity—perhaps 40 per cent.—may be found to be useless on account of internal defects. It is now often imported in sawn planks, which results in a considerable saving. It has the disadvantage of being heavier than yellow pine by about 75 per cent., but the one-sixth reduction made in its thickness reduces this to 45 per cent. The average length of teak planks is about 30 feet. It is the most durable of timbers; whatever the conditions, atmospheric or otherwise, it does not readily decay, shrink, or warp. Oak is also very durable, but it contains an acid (tannic or gallic acid) which has a corrosive effect on iron, and although in wood shipbuilding it was the timber most largely used, it is now rarely seen. Teak wood is only employed for the decks of high-class vessels, or those which trade in the Tropics, where pine might shrink and split from the excessive heat. On account of its smooth and oily nature it is apt to be slippery when wet; and this circumstance, and the fact of its weight, almost prohibits its use for the decks of warships, for where large numbers of men are actively engaged a reliable foothold is, of course, very desirable. In these vessels the upper deck is usually of Dantzic crown deals, a costly Baltic pine, coarse in appearance, but tough and durable.

Although the costliness of teak prohibits its general use, it is largely employed for those portions of pine decks where the prevailing conditions are apt to cause rapid decay or wear and tear. Pine, when in contact with iron and water, absorbs rust, and is then prone to decay, and particularly if it is the ends of the planks which abut on the iron, for the fibres, by capillary attraction, more readily absorb the rusty moisture. In a pine weather deck it is, therefore, the universal practice, and is required by Lloyd's rules, to fit all around it, next the gunwale, a **margin, or waterway plank**, of teak wood or greenheart. The latter is a harder wood than teak, but it is not readily procured, and is now rarely used. Pitch pine is sometimes used for the margin plank of decks other than the upper deck, but it is very inferior to teak, and is liable to split, especially when in broad planks. Towards the bow and stern the margin plank is checked as shown in Fig. 19, Plate 56, so that the ends of the deck planks may not abut thereon with too slender a point, for if they did they would split under the caulking tool. Care should be observed, in small vessels, that the breadth of the stringer plate at the bow and stern is sufficient to afford support within the margin plank for the ends of the deck planks.

In high-class vessels, having pine upper decks, a **boundary plank** of teak wood is generally fitted around all iron deck erections, houses, casings, hatchways, masts, ventilators, etc. (Fig. 20). Teak planks are also very commonly fitted on the central portion of the deck under and forward of the windlass, to take the chafe of the cables and to strengthen the deck against the pull and vibration of the windlass. In sailing-ships a broad plank of teak wood is generally laid all fore-and-aft by the sides of the hatchways and deck houses, which, as already noticed, stiffens the deck at the ends of these parts and is less liable to decay than yellow pine in way of the various eye and ring bolts, required for lashings and running gear. Where the steam pipes to the winches, etc., pass over the deck, it is common to fit, directly below them, a broad plank of teak wood, for when exposed to heat and moisture soft pine soon decays; in some cases a cemented gutter is substituted for wood at these places (Art. 168). When winches and bollards sit on a wood deck, a doubling or sole piece of teak, about 2 inches thick, is usually interposed, to provide a stiff foundation, and protect the deck planks.

Art. 338. Yellow-pine deck planks vary greatly in quality; the best are quite free from knots, and make a beautiful white deck. They vary greatly in length; 36 feet is about the average, but 40 or 50 feet is not uncommon. They should have few—if any—**knots**, and none at all of the objectionable sort which may become loose and cause rents in the planks. Knots on the upper surface of a deck are objectionable, for although not necessarily hurtful to the planks, they form hard points and do not wear down with the surrounding surface.

Deck planks should be quite free from **sap wood**. As this occurs under the bark of the tree, it is only found in the outer planks of the log, due to the removal of too thin an outer slab. Sap wood is of a pale or greenish colour, it is spongy and absorbent and readily decays, and in doing so affects the contiguous timber. They should also be free from **shakes** or open rents in the grain of the wood. Shakes are chiefly found in those planks which are cut from the outside of the log, due, it may be, to long exposure of the unsawn log to the weather; or they may be caused by too rapid seasoning or drying of the timber in ovens. They usually indicate a coarse, incompact grain, due to rapid growth of the tree; this effect of rapid growth is particularly noticeable in Oregon pine, different logs of which, when viewed in section, varying greatly in the density or closeness

of their growth rings. In laying a deck, care is, of course, observed to place the best side of the planks uppermost, for small surface shakes or knots, when below, or in the seams, are comparatively unimportant. Usually it is only the end of the plank that is shaky, and so, by reducing its length, the bad portion may be removed; very commonly, however, to save material, or where length is needed, the workmen remove too little. Shaky butts are the most common defect in a deck; it is a very objectionable one, for it greatly increases the marked tendency to decay at these places.

Art. 339. Oregon pine is straight in the grain and free from knots. It is procurable in very long lengths, often twice that of yellow pine. The great length of Oregon-pine logs makes them very suitable for masts and spars, and they have the advantage of being considerably lighter than pitch pine, the timber generally used for this purpose; as a rule, however, they are not found to be so durable. When employed for decks it is somewhat objectionable on account of its large, incompact grain, which causes the growth rings to separate or split away from each other. This fault may be minimized, however, by so placing the planks that the surfaces of the growth rings lie vertically (Fig. 27, Plate 56), for then they are squeezed together against opening tendencies by the contiguous planks and the clamping effect of the caulking. Lloyd's rules require Oregon-pine deck planks to be disposed in this manner.

Art. 340. Pitch pine is harder and tougher, and can withstand more wear and tear than yellow pine, and for these reasons it is generally preferred for the decks of cargo vessels. A pitch-pine deck usually presents a rough surface, and, owing to its resinous nature, it absorbs and fixes dirt, circumstances which make it unsuitable for the decks of passenger vessels. A serious objection to this material is the liability of the planks, when not properly seasoned, to develop shakes, which in time may become rents and cause leakiness in the deck. Although a shake on the upper surface of a plank may not appear below, it may, nevertheless, cause leakiness, for it may pass diagonally into the seam below the oakum. Broad planks are more liable to split than narrow ones, the latter being better clamped by the contiguous planks, and for this reason pitch-pine planks should not be broader than 5 inches. Lloyd's rules specify this as a maximum.

Art. 341. The **seasoning of timber** is the gradual drying, or elimination of its natural juices. If not thoroughly seasoned it shrinks, and is liable to decay when covered up or confined. Shrinkage of the planks of a deck after laying is, of course, very objectionable, for, with the gradual opening of the seams and butts, recaulking becomes necessary, and this, when the seams begin to open on the underside, is never quite satisfactory. Seasoning may be natural or artificial. When the former, the planks are simply stacked and exposed to the air. Deck planks of yellow pine, if 4 inches thick, should lie about six months after sawing, but when thinner a lesser period may suffice. Pitch-pine planks should season for at least six months, for they are resinous and do not dry rapidly, and as they are liable to split during the process, a long period of seasoning is a good test of their fitness for a deck; and Oregon-pine deck planks should also season for at least six months, for they also are liable to split. Lloyd's rules specify these periods of seasoning. When seasoned artificially, the planks are stacked in sheds, or "ovens," in which the air is kept at a high temperature; they then dry much faster, but if the heat is too great (it should not exceed 120 degrees Fahr.) they are apt to warp and split, and some of their natural properties may suffer. In the building of a vessel the sawing of the deck planks should be the first operation, preceding even the laying of the

keel. After the planks are sawn they are planed; this is done in a machine which operates on all four sides simultaneously, and as all planks pass through the same machine they are identical in breadth and thickness. Many shipyards do not saw their own deck planks, but buy them, planed and finished, from a saw-mill.

Art. 342. The **bolt holes for the deck planks** may be punched in the beams when these are being made, or afterwards, with a bear, when the beams are erected and the planks are lined off. If punched first they should, of course, be carefully spaced, so as to fall at the centre of each plank; and if the exact breadth of the planks is known, there is little difficulty in securing this result, for all are parallel to the vessel's centre line; and, in the fairing of the framework of the hull, the centres of the various beams (recorded by a nick) are, or should be, kept strictly in line. In the case of wood sheathing the bolt holes in the deck plating are placed close to each beam (Fig. 20, Plate 56). Here, also, they may be punched before the plates are fitted, and if the work is carefully done they should fall fairly in the centre of each plank (Art. 517). Often, however, they are inaccurately spaced, and in many cases, therefore, to ensure fair holes, they are drilled after the plating is fitted and the planks are lined off, electric or pneumatic drills being conveniently used for the purpose. When laying the deck, the planks first dealt with should be those on either side, halfway between the centre line and gunwale, for then any slight difference in the spacing of the holes and the breadth of the deck planks will be distributed, and be nowhere so pronounced, *i.e.* there will be a better average fairness in the holes.

Care should be observed in laying the first planks, to place them in a perfectly straight fore-and-aft line, for then, of course, all the others will be fair. In yachts, for the sake of appearance, the planks are often tapered towards the bow and stern, in which case the position of their edges is first lined off on the beams with chalk, and each plank tapered to suit. The actual **work of laying a deck** is simple: three or four planks, when placed in position, are clamped close together by wedges (see Fig. 18, Plate 56). If they cross over diagonal tie plates, etc., these are pencilled in from below, and the planks turned up and checked; the beams are then thickly painted, the planks relaid, the bolt holes bored up from below, the holes enlarged for the dowels, the bolts driven down, and the nuts hove up below. It is important that the weather should be dry when laying decks, for if the planks are swollen by moisture their subsequent shrinkage may greatly prejudice the efficiency of the caulking. Sometimes, for instance, in laying the decks of two sister vessels, an extra strake of planking may be introduced in one of them, if, in her case, the weather happens to be dry during the work, and in the other, wet.

Art. 343. The usual arrangement of **deck bolting** is shown in Figs. 18 to 24, Plate 56. Planks of ordinary breadth receive one bolt at each beam. If over 6 inches broad, Lloyd's rules require two bolts, one of which, if the breadth does not exceed 8 inches, may be a square-headed, wood screw, hove up from below. If more than 8 inches broad, both must be through bolts. Double bolting is, therefore, only found in broad margin planks and the like. In cargo vessels having plated decks the wood sheathing required in the crew's forecastle and cabin spaces is often fitted in broad 12-inch planks, held down merely by a bolt near either end, the surface being lightly caulked and payed. In the case of thin shade decks, and the decks of steel yachts, the planks are usually fastened from below by wood screws. Lloyd's rules for the diameter of deck bolts is $\frac{5}{8}$, $\frac{9}{16}$, and $\frac{1}{2}$ inch, according as the planks are 4, $3\frac{1}{2}$, or 3 inches thick. They are

always galvanized, for if not they would rust and discolour the wood. Even galvanizing is not a perfect preventive, for part of the zinc covering may be broken off when driving down the bolt. In the majority of the bolts this does not matter much, for when well covered up by the dowels water has no access; in those at the butts, however, water may be absorbed by the fibre of the wood, in which case the rusting of an imperfectly galvanized bolt accelerates the decay of the plank. This is one of the principal causes of decay in the butt-ends of old planks. The bolt heads should be sunk from 1 to $1\frac{1}{2}$ inch below the surface (Fig. 22) so that when the deck is worn thin they may still be covered by the dowels. To prevent the bolts from turning when heaving up the nuts, they are formed with a square part under the head, or the head may be slotted. The nuts are usually square, but in cabin spaces, where appearance is studied, they are usually hexagonal. Before driving a bolt, a *gromet* (*i.e.* a thread of oakum dipped in thick paint) is wound around it under the head, so as to ensure watertightness independently of the dowel, the latter also is dipped in thick paint before it is driven.

The enlargement of the upper part of the bolt holes for the **dowel** is made by a centre-bit, furnished with a long cylindrical guide piece, which enters the bolt hole already bored (see Fig. 26, Plate 56); it should have no side play, otherwise the cutter is apt to tear the deck, make an eliptical hole, and prevent a proper watertight fit of the dowel. This is a common fault, and a serious one, for should water pass down to the bolt head it is very apt to cause local decay of the plank. Dowels should preferably be of teak wood, or else of pitch pine; when of yellow pine they are not often smooth and cylindrical, and are too soft to drive tightly into the holes. They are cut across the grain, for an end-grain dowel would form a hard point in the deck and could not easily be chipped flush. They are made expeditiously in a turning lathe, fitted with a chuck in the form of a tube, whose bore is the diameter of the dowel; it has teeth on its forward end, so that when pressed against a flat slab of wood it perforates it, and the dowel, passing up the chuck, drops out at the back.

In unplated decks the **butts of the planks** are placed on the beams; and as the upper flange of a beam is not sufficiently wide to admit of a bolt in the end of each plank, the latter are usually checked, so that one bolt may hold both (Fig. 21, Plate 56); otherwise they may be cut with a slight bevel (Fig. 22), but this does not give so perfect a clamping effect. At one time it was common to rivet small patches of plating on the beams in way of each butt, so that each plank might receive a bolt, well back from its end (Plate 23). The butts of the planks are usually the first parts to **decay,** due to water having access when the caulking is loosened by fore-and-aft straining or shrinkage of the planks, and the presence of the iron bolt in the sodden wood accentuates the decaying effect of the moisture. To guard against this, the butt fastenings should be kept well back from the ends of the planks; and the latter should be quite free from shakes, and should not, when laying the deck, be bruised and injured by hammer blows.

Art. 344. Before laying the planks a shaving is taken off the side of each one, near the upper edge, so as to provide an **open seam for the oakum** and for the caulking tool. The same effect is sometimes produced in the planing machine, but this deprives the ship-wrights of the choice as to which side of the plank they will place uppermost. In wood shipbuilding the recognized rule for the breadth of opening in the seams is $\frac{1}{16}$ inch for each inch in the thickness of the plank. Soft pine planks do not really require any opening, for the wood compresses

sufficiently under the wedging action of the caulking iron; the caulking is then no less efficient, and the thin seams improve the appearance of the deck; with closely fitted seams, however, more care is required in driving the oakum, for the caulking iron is apt to break the edges of the planks; this is particularly the case at the butts, and here, therefore, an opening should always be provided. When the seams are quite close the first thread of oakum should be untarred, for it enters easily and opens the seam for the others.

The **oakum** is usually driven down about half the thickness of the planks. In decks which have been frequently recaulked (owing to shrinkage of the planks) the oakum may ultimately be forced right through the seams (A, Fig. 27, Plate 56), in which case its solidity and the watertightness of the deck can never be assured. This is sometimes provided against by making a fore-and-aft groove in the sides of the deck planks (Fig. 28), for should the oakum descend so far as to enter this, it curls up and goes no further. In a deck that is well laid and well caulked all the seams should receive the same quantity of oakum, and should be, finally, of the same breadth; the planks should lie close together on the under side, and, of course, they should sit close on the beams. Oakum consists of tarred hemp, teazed into a flossy cord, termed a "thread." Usually three threads are driven into each seam. **Caulking tools, or irons**, resemble a thin, broad, blunt chisel (Fig. 25), the edge of the one used for finishing off has a V-shaped groove. The oakum is driven down until it is perfectly hard, and it should then lie about $\frac{1}{4}$ inch below the surface. When removed from a seam it has an appearance and consistency not unlike leather. In ordinary caulking a light, one-handed mallet is employed; in heavy work, as a final operation, a large *horsing mallet*, or *beetle*, is sometimes used. In horsing the seams two workmen co-operate, one swinging the beetle and the other holding the caulking-iron—with handle affixed. In wood vessels the seams of the thick outer planking are always horsed; but deck planks, unless they are of thick hard wood, do not require it. Some further observations on the caulking and durability of wood decks will be found in Art. 163.

After the seams are caulked they are **payed**; *i.e. hot pitch* is run in over the oakum. Pitch is made by boiling coal tar, which process, by evaporating certain constituent oils, causes it to solidify when cold. A superior pitch is made with *Archangel tar*; it is less brittle, and does not so readily become sticky in hot weather, and, being of a light colour, it is cleaner. In better class work *marine glue* is used. This is made with caoutchouc and shellac, dissolved in naptha; it is a strongly adhesive glue, impervious to water, and does not become sticky. Its adhesive properties are prejudiced by oil, so that this should not be employed, as is usual, for lubricating the caulking irons. In passenger vessels and yachts the promenade and cabin decks are sometimes payed with *white putty*; this gives an elegant appearance to the deck, but putty is not so efficient as pitch or glue.

Art. 345. If, in **heavy weather**, a large wave should fall on a wood deck, it **may start the caulking**; *i.e.* the deck planks may be so jarred as to loosen the hard oakum lying between them. In extreme cases the planks themselves may start, *i.e.* they may strain, or jump, relatively to one another, so markedly as to strain the bolting and rise from the beams. To provide against these effects, a weather deck should, evidently, be thick, especially when the beams are wide apart; the planks should be clamped to the beams by strong and tightly-hove-up bolts; the bolt heads should be large, and the gromets below them not too bulky. Old decks are more easily started than new, for in course of time the nuts of the bolts may loosen, and

the planks work up from the beams. And in old vessels a scale of rust often forms on the tops of the beams, which, by forcing the planks upwards and corroding the bolts, may break the latter. In some cases rust, over half an inch thick, may be found below the planks; in old vessels its presence on fore-and-aft tie plates may often be observed by a well-marked transverse undulation in the deck surface. To provide against it, all iron work should be thickly coated with paint, or Archangel tar and cement, before laying the deck.

Art. 346. Wood decks gradually become so **thin by wear and tear** as to require renewal. Lloyd's rules in this respect require a 4-inch deck to be renewed when worn down to 3 inches; a $3\frac{1}{2}$-inch when $2\frac{3}{4}$ inches; and a 3-inch when $2\frac{1}{2}$ inches. In many cases, however, they require to be renewed on account of **decay**. Local decay is often made good with **graving pieces**, *i.e.* neatly inlaid pieces of wood, about 1 inch thick. In old decks these are often numerous; in new pine decks there should, of course, be none; in those of teak they are not so objectionable, for teak is not so liable to decay, and an original defect (defects in teak wood usually take the form of hollow cavities) does not necessarily prejudice its durability. They are objectionable in pine decks because decay may proceed underneath them, and, not being observed, may ultimately cause leakiness. The objectionable character of a graving piece may sometimes be observed by stamping upon it, for in many cases this will cause dirty water to splutter up from below. Sometimes, where the wood upper deck may have become thin, or defective by decay, it is doubled with planks about 2 inches thick, fixed in place, each one over a seam, by galvanized screws or through bolts. To repair a deck in this way is, of course, less costly than to renew it.

Art. 347. Previously to caulking the deck, it is **planed**, so as to make all the planks flush. If laid on clinker strakes of deck plating there is often much material to remove, in which case it is dubbed down by the adze. Electric planing machines are now available for this work; they operate in much the same manner as a garden lawn mower, and save much time and hard labour. In passenger spaces, where the under side of a deck is exposed to view, it also is planed, and a nice appearance is sometimes secured by running a bead on one of the lower edges of each plank.

Light **shade decks**, not employed for promenading purposes, are usually of thin **feather-and-groove planking** (Plate 107). If the planks are broad and thin (say, less than 2 inches) they are usually covered with tightly stretched, waterproofed canvas, fixed in place by teak-wood and lead margins. In passenger vessels designed for the tropics, if the shade deck forms the roof of deck-house cabins, and is not itself sheltered by an awning, it is usually covered with feather-and-groove boarding, laid on bearers so as to leave a 3-inch space between (Fig. 13, Plate 56); when so arranged the sun's rays do not heat the roof proper of the cabin.

In many cargo vessels only a part of the weather deck is laid or sheathed with wood, the rest being plated. The wood portion is fitted where there is cabin or crew accommodation below, with a view to avoiding extremes of temperature and **sweating** (Art. 467). Across the end of the partial wood deck an angle bar is riveted, to form an abutment for the ends of the planks and take the caulking (Fig. 6, Plate 56). The caulking of a wood deck has a powerful wedging action, which tends to force the planks towards the gunwale; to provide against this, therefore, and relieve the bolts from side stress, a marginal angle bar should in all cases be provided to support the outer plank, and, at the same time, take the caulking. At the ends of bridge decks, etc., the exposed ends of the planks are covered with a teak-wood moulding, or they may abut on an angle bar, as shown

in Figs. 3 to 5, Plate 56; and a cross covering board of teak is fitted on the top to take the rail stanchions and awning-stanchion sockets. The fitting and caulking of the moulding shown in Fig. 3 should be carefully done, so that water may not pass along the seams of the planks and enter the cabin or other spaces within.

Art. 348. In wood ships the timber frames are planked on their inner surface as well as their outer; the inner planking, which is termed the "**ceiling,**" does not serve as a watertight inner skin, but is necessary for the structural strength of the hull. In steel and iron vessels ceiling planking is only fitted on the floors or tank top, as a flooring for the cargo; the vessel's sides are covered with open sparring (Plates 101 and 105). When stowing perishable cargo, it is not usually laid directly on the ceiling planking, but a layer of **dunnage wood** (waste pieces of timber of all sorts and sizes) is interposed. Dunnage wood is also used to fill up vacancies between the packages, so that they may not move and chafe when the vessel pitches and rolls at sea. In wood ships a thick layer of dunnage wood is particularly necessary; for as these vessels are apt to leak, and as the spaces below the ceiling are small, a comparatively small volume of bilge water might rise above it and damage the cargo. In some cases dunnage wood is useful as a means of elevating heavy cargoes, so that the vessel may not be too stiff and uneasy at sea.

In double-bottom vessels **ceiling planking** is not essential, for the **tank top** itself affords the necessary platform for cargo; it is usually fitted, however, for it may dispense with the necessity for dunnage wood, and is useful in protecting the tank-top plating and distributing the pressure of heavy cargo. It may be laid on wood bearers or grounds (Plate 105), so as to provide an air space, from 1 to 3 inches deep, between it and the tank top; or it may be laid directly on the plating. An air space is advantageous in that, should any water leak through the tank top, it may flow into the side gutters without wetting, or appearing above, the ceiling; and if, by chance, a large volume of water should accumulate in one of the side gutters, perhaps through choking of the pump at this side, it may flow across the tank top, under the ceiling, to the other gutter. When laid directly on the tank top, leakage water might, of course, rise above it, but inasmuch as there is very little chance of leakage, and as delicate cargoes are always well dunnaged, the circumstance becomes unimportant. In practice, therefore, it is now fairly common to lay the ceiling directly on the tank top, introducing, where required, fillings or pads for levelling purposes.

When laid on grounds the latter are disposed transversely, so that drainage water may flow across the tank top to the side gutters, and they should be neatly fitted so as to lie solidly on the plating. The planks may be fixed to the grounds by large driving nails, but sometimes they are laid down without fixture—singly, or in hatches. The ceiling is, of course, extended over the side gutters, and in order that the latter may be readily accessible for cleaning, it is arranged in hatches at this place, or in such a way as to be readily lifted. And small hatches are provided over the manholes in the tank top (Figs. 3 and 8, Plate 72). In cases where ceiling is dispensed with, the tank-top plating, being exposed to local pressure and to the wear and tear incidental to loading and discharging operations, should be made rather thicker than what it is ordinarily. This, however, is not always done. Although dispensed with elsewhere, it is usually retained below the hatchways, for here the tank top is exposed to blows from heavy weights, thrown or falling from above; and, of course, it must always be fitted over the side gutters (Plate 104). To hold the isolated planking in

position, marginal angles or short lugs are riveted to the tank top. In the absence of ceiling the manhole covers must be protected; they are usually sunk below the surface of the tank top in the manner shown in Figs. 6 and 10.

In vessels having ordinary floors a large portion of the **ceiling** is arranged in **portable hatches** (formed either of single planks or of two, about 9 feet long, tie-bolted together), which may be readily lifted for cleaning the bilges. The rest of the planking is bolted to the reverse bars. The term "limber board" is used to designate the strake of planking on either side of the centre keelson (Plate 101); in wood ships it differs from the ceiling proper, in that it is thin and portable, and of no structural value; in iron vessels it has no features distinguishing it from the rest of the ceiling. The ceiling should form a continuous surface, free from holes and crevices such as might allow small stones and sand from the ballast, coal, grain, or the like to fall through, into the bilge water. The presence of grain in the bilge is objectionable, for it swells and chokes the limber holes and pumps, and it decays and becomes very offensive. When carrying grain in bulk, a single rat hole may have extensive results. When there is no double bottom, stones in the bilges are objectionable in that they roll about and wear away the cement (Art. 472). In the coal bunkers and in holds in which bulk grain is carried the ceiling should be lightly caulked, or "chintzed," as it is termed. It extends to the upper part of the bilge, the enclosure of the bilge space below being completed by fitting wood chocks between the frames, and cement over these (see Plates 100, 104, and 105). In vessels having ordinary floors the planks contiguous to the keelsons, when fitted in contact therewith, require to be neatly fitted and notched in way of the numerous rivet heads; this work, therefore, is sometimes avoided by fitting them just clear of the keelson angles and filling the vacant trough-like space with cement (Plate 101).

Ceiling is usually $2\frac{1}{2}$ inches thick, in planks about 10 inches broad. It is generally of red pine, or Baltic red wood, but common white pine is often employed. As it is exposed to severe wear and tear, and to conditions favourable to decay (being covered up from the air, in a damp and often dirty environment), it requires more or less frequent renewal. Under the hatchways, where there is excessive wear and tear, it is sometimes made of American elm, or a doubling of this material may be fitted over the ordinary ceiling.

Art. 349. In some of the earlier iron vessels the sides, like the bottom, were entirely covered with ceiling planking; later this was found to be undesirable, for the condition of the ironwork could not be observed, it could not be cleaned and painted as required, and the space at the back of the ceiling afforded cover for rats. Accordingly, **cargo battens** (often referred to as "open sparring" or "spar ceiling") were substituted, which, of course, leave the vessel's side accessible at all times for cleaning and painting. The battens are usually of white pine, about 2 inches thick, in planks from 6 to 9 inches broad, placed from 9 to 12 inches apart. Their purpose is to protect the cargo from damage by impingements with the sharp edges of the frames or by contact with the sweating steel, and to protect the vessel's side. When carrying soft cargoes, such as cotton, wool, etc., which are stowed under pressure, vertical battens are sometimes nailed on the fore-and-aft sparring as a further security against contact with the sweating steelwork. Lloyd's rules require all vessels to have cargo battens in the cargo spaces, excepting those which carry only coal, ore, or wood, for such cargoes are not liable to damage, and, moreover, mere battens would not keep back coal. As regards the steelwork, it

would be advantageous to prevent contact with coal, and, for this reason and for cleanliness, the sides of small coasting vessels which may carry coal and general cargo alternately are sometimes closely ceiled. And in vessels which constantly carry grain in bulk the sides of the grain holds are often closely ceiled and the seams chintzed.

Cargo battens may be bolted to the reverse frames (at every third or fourth), or they may be fixed in portable fashion, by cleats (see Fig. 2, Plate 56). The latter method is the more usual; it is advantageous in that the sparring is easily fitted and may be taken down without trouble for cleaning and painting the steelwork. The cleats are bolted or riveted to the reverse frames, or they may be of the patent detachable pattern shown in Fig. 1. In course of time wood sparring breaks up and requires renewal, and in some vessels, to avoid this, bars of convex iron, about 3 by $\frac{3}{4}$ inch, are substituted, being either riveted to the reverse frames or secured like ordinary battens. They are particularly suitable in deep ballast tanks which are also used for cargo. In the cargo spaces of high-class vessels it is common to fit projecting wood ferrings on all salient angle bars, such as the bulkhead and tunnel stiffeners, hold beams, etc., so that packages of cargo pressing thereon may not be broken and cut by the sharp edges.

Art. 350. In **cabins and storerooms** the vessel's side is covered with **lining**, or cleading, of feather-and-groove boarding, about $\frac{3}{4}$ inch thick. In order to hold this in place, *ferrings* are fixed on the sides of the frames (by bolts, screws, or by small horizontal shores, or toms, from the adjacent frame), and the lining is then nailed to the ferrings (see Figs. 7 and 8, Plate 56). The lining directly below the sidelights should be fitted in a portable fashion, so that it may be easily removed for cleaning and painting the steelwork, for, owing to rain or leakage water trickling down from the lights, the shell plating is here particularly liable to corrosion; in old vessels it is sometimes rusted through in holes.

In well-finished cabins the underside of the deck overhead is covered with panelling, and the beams with mouldings, of yellow pine or base wood, enamelled white. All this joiner work may be secured in place by ferrings bolted to the sides of the beams; the panelling lying between these (if the deck is plated) being nailed to cross grounds, whose ends are supported by the ferrings (see Fig. 15, Plate 56), or ferrings may be screwed to the deck sheathing, through holes drilled in the deck plating (Fig. 11).

The **cabin bulkheads** are constructed in various ways. Those which form mere partitions between sleeping cabins are of feather-and-groove boarding, but when exposed to view, in passageways and saloons, they are either of polished hard wood or of pine, enamelled white. The method of constructing them is shown in Figs. 14 and 16, Plate 56. A shallow, rabbeted *cant* or *coaming* is fixed to the deck by screw nails, and over it, to the deck above, a corresponding *runner* or *lintel*. The latter, if disposed fore-and-aft, is fixed to the lower edges of the beams with lugs, or, if the beams are of tee-bulb pattern, with small tap screws screwed into the bulb, or by slotting the runner at the bulb and driving in wedges, as shown in Fig. 16. Between these two parts wood uprights are erected, at distances to suit the prearranged design of panelling, doorways, etc. The bulkhead proper is built in the joiner's, or cabinet-maker's, shop, in separate pieces, termed "frames," each one resembling a wide panelled door, of the proper dimensions to fit between a certain pair of uprights, the cant and the runner. To provide for the free passage of light and air into and out of the cabins, the upper part of the bulkhead, between the beams, may be of ornamental, cast-iron fretwork, or of thin expanded metal in the form of a fine trellis; or hinged fanlights may be fitted; and gratings are provided at the lower

part, usually in the doors. In passenger vessels having numerous cabins the outer bulkheads are usually of the well-known *jalousie framing*, the advantage of which lies in the circumstance that, while forming a substantial screen, it allows the free passage of air (see Fig. 17). In high-class passenger vessels the saloon bulkheads are often of the most elaborate description, composed of various polished hard woods, ornamented with carving and hand painting. As a rule, hard-wood panelling is made with veneer, for this, as regards durability and appearance, is little, if at all, inferior to solid wood.

As regards the **furnishings and fittings of the cabins**, so great is the variety in the matter of finish and artistic merit, and efficiency as regards compactness, etc., that no good purpose would be served by describing them. Formerly the sleeping berths, or bunks, were built of wood, as fixtures; now they are practically always of iron; their construction, as specialities, representing an important industry. As a rule they are arranged to fold up, so that through the day, when not in use, the cabins may be more roomy. And, for a similar purpose, the wash basins are of folding or collapsible type.

Art. 351. In most vessels there are one or more **deck houses.** In steamers one is always found at the front of the bridge deck, where it may serve several purposes: that of a steering or wheel house, a chart or navigating house, a companion or stairway entrance to the cabin spaces below, or of a sleeping cabin for the captain (see Plates 109 and 110). In most vessels the crew are berthed in the forecastle, or in the 'tween deck space directly below it. In modern sailing-ships they are usually accommodated in a deck house, which also contains the galley and donkey-boiler room (Figs. 1, 2, and 3, Plate 86). At one time deck houses were always of teak wood; now they are usually of steel or iron. A teak-wood house, when small, is built in the joiner's shop. Although nominally of teak wood, the sides are usually of feather-and-groove pine, sometimes in two thicknesses, with teak panelling nailed on the outside. The coaming, when of wood, is sometimes fitted to the top of the wood deck, but it is better to bolt it direct to tie plates riveted on the beams. Large wood deck houses are built in place, and they have usually an inner coaming of steel, and angle-bar frames and beams. To provide against side straining tendencies, a couple of diagonal stays should be incorporated with the end walls.

Art. 352. A **companion** may be described as an entrance and cover to a stairway leading from the weather deck to the cabin spaces below. The old-fashioned companion, shown in Fig. 12, Plate 56, forms an awkward kind of entrance, for one has to stoop more or less to pass through; when of wood, this is usually remedied somewhat by making the roof slide; when of iron, they are made higher. In modern steamers deck houses take the place of companions. The latter are still employed, however, for the entrance to the crew's quarters forward (Plate 110); when placed here they are of steel, for a wood companion, apart from its costliness and other disadvantages, might be stove in when placed near the bow. Part of the engine-room skylight is sometimes built as a companion, to give access to the engine room from the bridge deck. And in large passenger vessels portable wood companions are often fitted over a portion of the hatchways, as a supplementary means of access below, for the numerous second and third-class passengers.

Art. 353. As shown in Figs. 9, 10, and 11, Plate 56, there are three **types of skylight**; but besides these, there is the lean-to or dwarf skylight, commonly employed in passenger vessels for lighting the passage-ways and cabins in the 'tween decks (Fig. 5, Plate 8, and Fig. 21, Plate 75

and Plate 107). The skylight illustrated in Fig. 9, Plate 56, gives a handsome, lofty appearance to a saloon; and in many cases, to secure still further this desirable effect, a large open shaft, or well, like a deck house without bottom, is built over the saloon, and the skylight placed on the top. And in some large, ocean, passenger vessels, instead of an ordinary skylight, a lofty stained-glass dome is provided, protected on the outside by an outer casing of steel, having numerous bull's-eye lights; and electric lamps may be placed between the glass dome and the outer cover, so as to shed a pleasant radiance below. The engine-room skylight is usually built of thin steel, which, owing to the moist hot air of the engine room, is more suitable than wood, and makes a stronger, more durable, lighter, and less costly skylight.

CHAPTER XXIV.

Art. 354. Bilge keels, as their name implies, are keel-like projections on the bilge (Figs. 4 to 7 and 11 to 17, Plate 57). Their purpose is to reduce rolling, hence they are sometimes referred to as "rolling chocks." They have long been fitted in warships, but until comparatively recently were seldom adopted in ordinary merchant vessels. All vessels are liable to roll; the tendency arises, of course, from the heeling effect of broadside waves, each one as it passes tending to tilt the vessel over. Whether or not waves may cause excessive rolling depends on the correspondence of their "*period*" with that of the ship. The period of a wave is the time it takes to move its own length, from crest to crest. It varies with the square root of the length of the wave, irrespective of its height; the period of a wave 400 feet long is about 9 seconds, that of one 100 feet long about $4\frac{1}{2}$ seconds. The *period of oscillation* of a ship is the time occupied in making a roll, say, from port to starboard. If the waves encountered happen to have the same period as the double roll of the ship, then each one will give her a well-timed impulse, quickly increasing her angle of roll. The principle may be observed in a simple pendulum; if touched with a gentle impulse at the end of each swing, it will gain impetus and swing through larger and larger angles. It will be found that whether the angle of swing be large or small (within certain limits), the period is practically the same; and similarly with a ship, the period is much the same whether the angle of roll be large or small. If, on the other hand, the period of the waves encountered does not correspond with the double period of the vessel (due to their being too long or too short), there will be little tendency to roll, for as the tilting impulse will then occur at odd moments, the effect of one will defeat that of another; just as a pendulum, if subjected to haphazard impulses, may lose rather than gain momentum. A ship is not, of course, entirely helpless as regards the rolling effect of the waves, for by a slight change in her course she may shorten or lengthen their period, *i.e.* their apparent period as regards their movement past her. If her actual speed be equal to that of the waves, then, if she steam with them, none will pass her, their period in such case being infinite; if she steam parallel therewith, their period past her will be their natural period; and if she steam against them, half their natural period. A diagonal course will produce intermediate effects; and, of course, to cause rolling, the course must depart more or less from one directly end-on to the waves.

The **period of oscillation** varies in different vessels. One having a short period is more likely to roll and be uneasy at sea than one having a long period, for as the waves usually encountered have a comparatively short period, they are more likely to synchronize with the former; and, moreover, short waves are steeper and more effective in their tilting impulse. A vessel's period of oscillation depends on her stiffness and on her weight and the distribution of her cargo. Stiffness, or initial stability, is measured by the metacentric height, which is governed by

the vessel's form and proportions, her displacement, and the height of her centre of gravity. A broad, shallow vessel is likely to have a large metacentric height, and, in consequence, is likely to be stiff, to have a short period, and to roll, not necessarily through large angles, but in a violent and jerky fashion; but this, again, is dependent on the cargo stowage; if in light trim, the above effects are usually greatly accentuated; if heavy weights are carried in the upper 'tween decks, so as to raise the centre of gravity of the hull and contents, the stiffness or metacentric height due to her proportions and form may be nullified, she may become crank or even top-heavy, and, in consequence, comparatively steady under the more usual wave conditions.

As just noticed, a stiff vessel (*i.e.* one having a large metacentric height) is likely to have a short period and to be an uneasy roller. But not necessarily, for, if large and heavy, she may possess great inertia, which, of course, is incompatible with rapid oscillatory movement. And, while maintaining the stiffness, the period of oscillation may be lengthened by stowing whatever heavy weights are carried remote transversely from the centre line or axis about which the vessel rolls; *i.e.* by placing them towards either side, or by lowering some to the bottom of the hold and raising others—similar weights—by an equal distance upwards. Such procedure would not alter the position of the centre of gravity of the hull or the metacentric height, but, by increasing the vessel's moment of inertia, it would lengthen her period of oscillation. The principle may be observed in the familiar see-saw, in which the oscillations become slow or fast according as the weights are shifted from, or towards, the centre. This principle is a governing one in the design of warships. The very large beam of these vessels results in great natural stiffness, which in itself would lead to uneasy, jerky rolling, but owing to the heavy masses (armour, guns, and coal) disposed close to the sides, their great stiffness is not prejudicial; on the contrary, they may roll slowly and easily. In the later ironclads the metacentric height is about 3 feet; this is quite three times what is common in a loaded merchant vessel, yet their period of oscillation may be as long as 8 seconds for a single roll. In merchant vessels the period varies greatly, due to the wide difference in the form, proportions, weight, and cargo stowage; when loaded, the period of a small vessel may be 3 or 4 seconds, but that of a large one may be as long as 10 seconds. When in ballast trim the metacentric height of a full, modern, cargo vessel may be 5 or 6 feet, or three or four times what it is when fully loaded with homogeneous cargo; and as their period of oscillation is, therefore, very small, they are immensely stiff and uneasy at sea.

Art. 355. With a view to ascertaining the **value of bilge keels** in reducing rolling, some very interesting **experiments** were made by the Admiralty with H.M.S. *Revenge*, a first-class ironclad of 14000 tons displacement,[1] She was built, in the first instance, without bilge keels, and subsequently they were added, and, as is usual in warships, they were large, being 3 feet in depth by 200 feet in length, or about half the length of the ship. Rolling experiments were made in both conditions, and among other results it was found, that while, without bilge keels, an angle of roll of 13 degrees on either side of the vertical could be attained by merely moving the guns athwartship, an angle of only 6 or 8 degrees could be attained after bilge keels were fitted, and only when the heeling effect of the guns was supplemented by that of 400 men running across the deck at

[1] See Sir W. H. White's paper in the *Trans. Institution of Naval Architects* for 1895; also see Mr. Andrew Young's paper, *Trans. North-East Coast Institution of Engineers and Shipbuilders* for 1894-95.

suitable intervals; that is to say, the angle of oscillation was reduced by the bilge keels by about 50 per cent., and that under a greater oscillating influence. Again, while, in the absence of bilge keels, the vessel rolled—of her own accord—some 45 times before the angle of roll diminished from 6 to 2 degrees, with bilge keels, the same loss of movement or momentum occurred after only 8 rolls; that is to say, a state of comparative rest prevailed in about one-sixth of the time. These results were not anticipated, and until recently the action of the bilge keels in producing them was not understood. Formerly their steadying effect was wrongly assumed to be simply that due to their resistance as flat surfaces moving laterally through the water, like a submerged paddle, which, when the speed is 1 foot per second, has been found by experiment to be only about 1·1 lb. per square foot, and to vary with the square of the speed. But the retarding force known to be operating in the case of the *Revenge*, on the basis of her known momentum, would require that the factor 1·1 should be some ten times greater. Now, it appears that their powerful extinctive effect on the rolling is due to the discontinuous motions, or under-water currents which they set up.[1]

Similar experiments were made with the vessel steaming ahead, when it was found that the steadying effect of the bilge keels was even greater than when at rest, and the more so the greater the speed. This may be explained by the fact that, when the vessel is steaming, the bilge keels constantly encounter undisturbed water, all of which they have to impress with lateral motion, whereas, when the vessel is at rest, they only put in motion the limited mass of water included in their length. Another important point was noted, namely, that notwithstanding the additional surface offered by the bilge keels to the retarding effect of fluid friction, the vessel's speed and resistance were not appreciably affected. Indeed, experience with merchant vessels indicates that, in heavy weather at sea, the steadying effect of bilge keels is beneficial as regards the average speed on a voyage. As regards steering qualities, the presence of bilge keels is again favourable, conducing to greater steadiness on a course, and reducing the diameter of the turning circle.

In warships rolling tendencies are very objectionable, for each roll may expose the unprotected side below the armour, and it is evident that the ship which is steadiest is the most likely to aim well with her guns. For these reasons, warships are always provided with large bilge keels. In sea-going merchant vessels the tendency to roll was formerly regarded as a characteristic more or less inevitable and unimportant. The steadying effect of bilge keels was considered a doubtful matter, and, as they are somewhat objectionable in themselves, it was rarely thought expedient to fit them. They are detrimental in increasing the first cost and weight of the hull, they are liable to damage and may be an inconvenience in dry dock. Now, however, with more certain knowledge of their beneficial effects, they are a common feature in both passenger and cargo steamers. And many of the older vessels, which have proved themselves heavy rollers, have been provided with bilge keels, and always with good results in improved behaviour at sea. Sailing-ships do not roll, for they are held down to leeward by the wind; they do not, therefore, require bilge keels.

Art. 356. In vessels having the usual full 'midship section and sharp bilge, the **bilge keels** must be **comparatively shallow**, for if large, as in warships, they would project beyond the line of the bottom or side, in which case, as they would be the first parts to take contact with the ground

[1] See Mr. G. H. Bryan's paper, "*The action of bilge keels*," *Trans. Institution of Naval Architects*, 1900.

or with quay walls, they would be readily damaged. In ordinary cases they do not exceed 12 inches, a common size being 9 or 10 inches. When a depth of a foot is exceeded they are usually constructed of plates, as shown in Fig. 17, Plate 57. A bilge keel of this formation has great lateral strength—a necessary quality, for, when so large, the mere side pressure caused by rolling becomes a force of considerable magnitude. In comparing the shallow bilge keels fitted in merchant vessels with those adopted in warships, it might appear that they would be comparatively ineffectual in checking rolling. But this does not follow, for merchant vessels have usually a much shorter period, so that, rolling more quickly, their bilge keels move faster through the water. Further, although when heavily laden a merchant vessel may roll slowly and acquire momentum so great as not readily to be destroyed by small bilge keels, it is unusual for serious rolling to occur under such circumstances. The need for bilge keels occurs principally when a vessel is in ballast, for she is then stiff and at her worst as regards rolling, and it is just under this condition that bilge keels are most effective.

Bilge keels are not usually longer than half the length of the vessel, a common proportion is about one-third of the length. It is on the bilge amidships that they are most effective, for as they are here most remote from the central fore-and-aft axis about which the vessel rolls, they sweep through the water with the greatest velocity, and, consequently, meet with the maximum of resistance. In full cargo vessels they are usually only fitted on the straight 'midship region; in which case the angle bars, etc., do not require to be bent, and the constructive work is simplified. They are worked parallel to the plate landings, at about the middle of the curve of the bilge. In a fine-lined vessel, where they may have a considerable fore-and-aft curvature, they are usually disposed in such a way that, when viewed fore-and-aft, they appear as a straight diagonal line, their entire surface lying in one plane; it is supposed that they do not then interfere with the fore-and-aft stream-like flow of the water past the ship.

Bilge keels are particularly liable to be **bent and torn.** The most fruitful cause of damage is the coming in contact with quay walls, due to the vessel heeling over when lying alongside with her bilge against the wall. Then, in some harbours there exist, close to the wharfs, the stumps of old piles, and these also are a common source of damage to bilge keels. Damage may also be incurred through grounding, but very commonly, though the bottom of the ship may be damaged, the bilge keels are uninjured. Injury to a bilge keel may be accompanied by serious consequences, for, should the rivets connecting it to the shell be affected, the water may flow into the ship. In warships, to preclude this, the rivets are screwed through the shell plating, and their points within provided with nuts, so that, however extensive the damage to the bilge keel, the watertightness of the shell may be unaffected. In ordinary cases the danger is well provided against by making the root, or part of the bilge keel in immediate contact with the shell, particularly substantial, and riveting it with superior firmness, for then the disruptive effect of an external force is usually limited to the less substantial outer part, bending or tearing it away, but leaving intact the remainder. The efficacy of this provision is constantly observed, for damage to bilge keels is a most common occurrence, yet rarely does it affect more than the outer part.

Bilge keels are formed in different ways. A common **formation** is a bulb and double angle bars (Fig. 12, Plate 57). It is both substantial and secure, for while the bulb bar is well supported, it, only, in case of damage, is likely to be bent or torn. To repair this type of bilge keel,

however, is not easy, because, when the outer part of the bulb is torn off, it is a difficult matter to cross-cut and remove its stump from between the two angles. The substitution of a tee bar for the double angles avoids this difficulty (Fig. 13); and if the tee bar is stouter than the bulb, the formation is an excellent one. In some cases the bulb on the outer edge is dispensed with (Fig. 11); and this is advantageous in improving the efficiency of the bilge keel, the sharp edge increasing its lateral resistance. Sometimes a bulb-tee bar is adopted (Fig. 15); it is strong and secure, but, owing to its stiffness and rigidity, a close fit on the shell, whose surface, owing to the lap joints, is more or less irregular, is not so assured. In many cases a single-angle and bulb-bar formation is adopted (Fig. 14); it is less secure than those just noticed, because of its limited base of attachment to the shell; but if the angle is considerably thicker than the bulb bar, and if the rivets connecting it thereto are widely spaced, say 50 per cent. further apart than those connecting it to the shell, it is unlikely that its integrity would be affected by the carrying away of the bulb. It should be observed, however, that a wide spacing of the rivets is objectionable in that they are then very apt to become loose and to require periodical renewal; and if their renewal is neglected, the bulb bar is likely to be torn off at sea. A bulb-angle formation is sometimes adopted (Fig. 16), but it is not a desirable one, for should it bend or tear it may do so so close to its root as to injure the shell riveting. It is also open to the same objection as the bulb-tee, namely, that its great stiffness may preclude a close fit to the shell and sound riveting.

Bilge keels may contribute very considerable longitudinal strength to the hull; due to their own sectional area and to their stiffening effect on the shell plating. Their efficiency in this respect, however, is evidently dependent on the security of their joints, and so, if longitudinal strength is desired, these should be properly connected. As a rule the joints receive little attention; those of the angle bars are not usually connected, and those of the bulb bars have usually only a small strap. As regards the primary duty of a bilge keel, special strength in its joints is, of course, unimportant.

The **rivets connecting the bilge keels to the shell** are closely pitched, usually about four diameters. Their soundness is very important, for, unlike the ordinary shell rivets, their watertightness is dependent on the tightness of the shank or head, and not on that of their clinched points. To ensure sound rivets, three-pliers are avoided by spacing them clear of the frames; they cannot be avoided at the end joints of the shell plating, and as the riveting of the bilge keel may disturb the caulking of the joints, a stop-water must be placed in each one. If the rivets in the shell joints are made use of for connecting the bilge keel, the holes must not be countersunk; very commonly they are, inadvertently, in which case they should not be used, but other holes should be drilled between the existing rivets. Sometimes, to provide against leaky rivets, a strip of felt is fitted the whole length of the bilge keel, and sometimes all edges of the angles are caulked. Tapered liners may be fitted where the angles pass over the laps of the shell plates (Fig. 5, Plate 57); otherwise the angle bars may be joggled (Fig. 6), or the ends of the overlapping shell plates may be slotted (Fig. 4). Sometimes the shell bar is cut at each joint, as shown in Fig. 7. The better to ensure watertightness in the rivets, the heads within are sometimes countersunk, and well hammered up, but pan-headed rivets are the best. The ends of the bilge keel are tapered into the shell, and as they are liable to be caught and torn by the vessel's cable, it is well to strengthen them by bending round the bulb to meet the shell

(Fig. 7); to do so does not involve welding work if the material removed, to form the taper, is cut from the heel of the bulb plate.

Coasting vessels engaged in a trade which requires them to lie alongside quay walls, or frequently to pass through narrow dock entrances, are usually provided with a timber **Fender**, so that it, instead of the thin shell plating, may take the pressure and blows incurred by forcible contact with the walls (Fig. 18, Plate 57). In the case of vessels not so provided, cork or rope fenders, or round sectioned pieces of timber (short cuttings from a spar), are hung between the hull and the wall; these, however, do not distribute the pressures, and, unless the shell plating is very thick, it is apt, if there is any sea running, to become badly indented, and the riveting loosened. The fender usually extends for about two-thirds the vessel's length amidships, on one or both sides, and is placed just above the load waterline. It is formed of a stout log of American elm, scarph jointed, and bolted by vertical bolts through the horizontal flanges of two angle bars riveted to the shell, one above and below; and an iron rubbing plate, about 1 inch thick, is fixed on the face of the log by short driving bolts, or "dumps." The timber must not be bolted through the shell, for the bolts would strain and become leaky under the crushing pressures sustained by the fender. When waves strike upwards against the lower surface of the fender, they cause concussions which are very objectionable, especially in passenger vessels; the intensity of the blows is lessened to some extent by sloping the lower surface upwards, as shown in Fig. 18. Should a vessel, when lying against a wall, take an outward list, the bilge, as well as the fender, may take contact with the wall, and, accordingly, to avoid damage to the bilge plating, it is common to fit a thick external doubling plate at this part.

CHAPTER XXV.

Art. 357. To protect the crew and passengers, an **open rail** or a **close bulwark** is fitted around the weather deck (Figs. 5 and 8, Plate 59). A bulwark gives better protection than a rail, for it prevents, to a large extent, waves from breaking on board; it gives, therefore, more security to the deck fittings, hatches, ventilators, etc., and, by keeping heavy masses of water off the deck, helps to maintain the vessel's weatherly qualities. The nearer the weather deck to the sea level, the greater the chance of its being swept by the waves, and so the more the need for a bulwark. They are, therefore, fitted in all low-freeboard vessels; in the case of shelter decks, awning decks, and deck erections an open rail suffices; as spar-deck vessels may load deeply, they have usually a bulwark.

In **sailing-ships** a **bulwark** is particularly necessary (Plates 100 and 101), for, when inclined by the wind, the lee gunwale may be almost level with the water surface, when, of course, the deck is readily swept by the waves. It also affords stability or stiffness, for if, when heeled over, the sea were to overwhelm the lee side of the deck, the weight of water would tend to increase the heel, acting, for the moment, like badly-stowed additional cargo; if kept off the deck by a bulwark, the same force would be present, but it would be a buoyant one, tending to right the vessel. Of course, a bulwark cannot keep back all water, for this would pass through the open scupper holes and mooring pipes, but it may do so temporarily, at a critical moment, when the vessel is suddenly forced over by a squall. A bulwark on the weather side is also useful, for, under its protection, the crew are able to move fore-and-aft, however fierce the wind and sea.

Although a bulwark is useful in keeping water off the deck, it has the disadvantage of retaining that which may find its way over it. But the chance of a dangerously large volume of water passing over the bulwark is small; and, if it did, the greater part would at once disappear, owing to the sheer of the deck and the rolling and pitching of the vessel; and, moreover, the evil is minimized by providing numerous "*freeing ports*," *i.e.* openings in the bulwarks, having flaps, hinged in such a way that they may open outwards under pressure of deck water (see Fig. 3, Plate 59).

In a **well-deck vessel**, the well between the forecastle and bridge (Fig. 2, Plate 26) is particularly liable to receive large volumes of water; and to retain them, for it is short, its bulwark is high, and it is bounded by a cross bulkhead at either end. Here, therefore, freeing ports of extra large size are required, because if insufficient to clear the well quickly, the vessel, having a heavy mass of water on board, would, in effect, be overloaded, with a very undesirable trim by the bow; and, further, the hatchway at this part, if entirely submerged, might not entirely exclude the water from the hold. So important is this matter that in these vessels the **freeing-port area** is taken account of in the assignment of the **freeboard.**

The area should, of course, be proportionate to the length of the well, and be relatively larger in short wells, for not only are these more likely to hold deep water, but they imply a smaller freeboard. Lloyd's requirements, and the standard adopted in the Load-line Act, is an area of 1 square foot (on each side) for each 5 feet in the length of the bulwark, for wells over 65 feet long; for shorter wells it becomes greater, increasing to 1·5 square foot in the case of one 30 feet long.

For bulwarks other than the above there is no fixed practice as to freeing-port area. In steamers the length of the bulwarks is reduced by the deck erections, and here the usual practice is to provide a freeing port at each end of each portion, and one or two intermediately if the distance between is great. The most effective position is, of course, towards the ends of the bulwark, where, owing to the cross bulkhead of the deck erection, there is a natural tendency for water to accumulate; and more particularly towards 'midships, where the deck is at its lowest level. In sailing-ships freeing ports are fitted at intervals of 40 or 50 feet, the larger number towards 'midships and the after end.

Art. 358. Freeing ports vary considerably in their design (see Figs. 3, 10, 12, 13, Plate 59). When of large size the lower part may be hinged to the upper (Fig. 10), so that it may open to a small body of water. In some, the hinges are placed at the forward end, so that the port may swing open horizontally. As it is important that the door should open readily to a small pressure of deck water, the hinges should be well constructed, with brass pins to avoid rusting and stiffness. Sometimes link-like eyes are substituted for hinges, which, while very strong, ensure at all times easy movement of the door. Bolts or catches are provided for use in fine weather, to hold the door shut and avoid incessant jarring. In some cases no doors are provided, only a permanent grille of round-iron bars, fixed in an angle frame. The doors are liable to violent blows from the waves, and, should heavy weather be encountered, they are often damaged; they and their mountings should, therefore, be substantial, and the corners of the opening should preferably be cut with a radius, for when square they are apt to form starting points for cracks in the bulwark plate.

Art. 359. The **height of the bulwark** varies greatly. In sailing-ships, $4\frac{1}{2}$ feet is perhaps the average, but towards the bow it usually sweeps upwards, for the sake of appearance, and to give better protection at the ends. In steamers it may be no higher than an open rail, or about $2\frac{1}{2}$ feet; but when the distance between deck erections is very short, as in the well of well-deck vessels, it may be of their height, so that when viewed externally there is no apparent discontinuity in the topside plating.

In **sailing-ships the bulwark** must be specially strong, for as the leeward one is usually close to the sea level, it is exposed to blows and pressures from the waves. Steamers, unlike sailing-ships, do not often lie at the mercy of the waves, and their bulwark is shorter and lower. Bulwarks are of thin plating, usually $\frac{5}{16}$ inch, single riveted to the upper edge of the sheer strake; but they are strengthened by the fore-and-aft rail, and by supporting **stays** (see Plates 100 and 101). Lloyd's rules require the bulwark stays of sailing-ships to be not further apart than 5 feet, and that they shall support the bulwark about mid-height as well as at the main rail, the thin bulwark plating being doubled in way of them. The plates of the bulwark are so arranged that their joints may fall in way of every second or third stay, their buttstraps or laps forming the necessary doublings; special doubling straps are then introduced for the intermediate stays, but sometimes angle-bar stiffeners are advantageously substituted (see Fig. 4, Plate 59).

Various forms of **bulwark stays** are illustrated in Plates 59 and 100 to 104. That formed of a bulb bar is particularly strong and efficient, and is now often adopted. Formerly the heels of the stays were stepped on the gutter-waterway bar, as in Figs. 4 and 11, Plate 59. This disposition is advantageous in that the stay has then a maximum of spread or inclination, but it has some practical objections, for the thick forged heel of the stay rarely fits with precision on the bar and as the rivets cannot pull it close, and as all-round caulking is impracticable, watertightness is not always assured. When the connection is to the vertical flange (Fig. 4), the pushing and pulling of the stay may strain the rivets, or, by pulling the flange of the angle bar away from the wood deck, cause leakiness of the caulking of the margin plank. As valuable cargo has often been damaged by water leaking through the deck at the heels of the bulwark stays, Lloyd's rules now require those in sailing-ships to be connected to the stringer plate by four tap bolts, having nuts hove up on their points below, for in this way perfect and permanent watertightness is assured. In steamers the staying of the bulwarks is less important; the stays are either of round, T, or angle bars, placed about 6 feet apart.

In **yachts, bulwark stays** are usually avoided, the bulwark being supported by extending every second or third frame through the upper deck. A continuous gunwale bar is then fitted within the frames, as in the case of a lower deck, and watertightness obtained by filling the spaces between the frames with Portland cement or wood chocks, neatly fitted and caulked. Cement is found to answer well, the watertightness being perfect and permanent; wood, of course, is liable to decay. In some large sailing-ships the bulwark is constructed in this way, the reverse frames being carried up as well as the frames, and the gunwale made watertight with cement. Although a bulwark of this kind is strong and perfectly efficient, it is objectionable in that, should it be damaged, the watertightness of the deck at the gunwale may suffer; an ordinary bulwark, being merely an added part, might be torn off without serious results.

Art. 360. The upper edge of the bulwark is stiffened by the rail. This is usually of bulb-angle section, but various other formations are adopted. In sailing-ships there are two rails, the **upper or top-gallant**, and the **lower or main rail** (Figs. 4 and 11, Plate 59). The main rail must be strongly fashioned, for it takes various attachments for the standing and running rigging: belaying pins, fair-leads, eye-plates, small bollards, crab winches, etc. It used to be formed entirely of timber, connected to the bulwark plating by an angle bar and by the tops of the stays. Now it is always of steel (a large channel bar being conveniently employed), with a face piece of hard wood, usually greenheart, to take the various fittings for the rigging. This rail forms so rigid a line in the thin bulwark plating, that it is apt to show on the outside as a hollow or ridge, especially as the bulwark plating above, in the absence of transverse stays, is liable to be bent inwards by blows from the waves; to support the upper part of the bulwark, therefore, small stays are sometimes fitted from the main to the topgallant rail. The part of the bulwark above the main rail is termed the "topgallant bulwark;" formerly it was regarded as an unimportant part, and, while the lower portion was of iron, it was often constructed of light boarding. Bulwark stays of special strength are usually introduced in way of the rigging, having large L-shaped upper palms to hold the main rail against the stresses due to the attachment of the running rigging. The main rail is very commonly increased in breadth at this part, in order that the rigging *chain plates* may pass through it, and to secure convenient belaying pins. Although the chain plates may traverse the rail,

they should not, when fixed at the proper inclination, impose upon it any transverse stress (see Plate 100).

Art. 361. In steamers, to avoid the necessity of lifting cargo over the bulwark, large **gangway doors** are sometimes provided at each hatchway. Formerly they were usually in halves, hinging forward and aft, but now the more simple plan is generally adopted of hinging them downwards on deck (see Fig. 1, Plate 59). When the bulwark is very deep, as in the well of some well-deck vessels, the doors are often divided horizontally, so that, when the upper doors are open, the lower may form an ordinary low bulwark. The ends of the bulwark at the doors must be particularly well stayed (Fig. 10), for they are liable to blows from passing cargo, and there is a natural transverse weakness due to the discontinuity. In the details of their design gangway doors vary considerably. When closed they are locked in position by sliding bolts and by a central stay, holding both doors if there are two. The bulwark is usually designed as a fair continuation of the surface of the hull below; in small tug boats, however, it is very commonly set in at an angle, so that when alongside of other vessels it may escape contact.

Art. 362. Provision must be made for passing lines overboard from various points, to moor the ship when lying alongside a quay, and for shifting her in harbour. To pass these lines through the bulwark, **mooring pipes** are provided, usually four on each side, one at either end of the bridge and one near the poop and forecastle (see Fig. 9, Plate 59, and Figs. 1 and 2, Plate 109). They may suffer great stress, for, through surging of the ship in a tide-way or river, stout wire lines, having a breaking strength of many tons, are sometimes pulled asunder. They are usually of cast iron, and the thin bulwark plating should be doubled in way of them, for if it yielded to the strain the pipe might fracture. To make fast the mooring lines, large cast-iron **bollards** or **timber heads** are bolted to the deck, in such a position as will give a straight lead (end-on as regards the bollard) to the mooring pipe (see Figs. 9, 14, 15, 16, Plate 59, and Figs. 1 and 2, Plate 109). Similar bollards—sometimes termed "bits"—are provided on the forecastle deck, for towing as well as mooring purposes. Bollards should be well secured to the deck; if the deck is not plated, a special plate is fitted at this part. Often they are merely bolted by the deck plating, with or without a foundation or sole piece of wood (Fig. 9, Plate 59), but it is well (especially in the case of large towing bollards), to fit stiffening bars between the beams (Fig. 15), or else a stout chock of timber, with or without a plate on its lower surface (Fig. 14); a wood chock not only gives solidity to the deck, but, by increasing the length of the holding-down bolts, gives a certain amount of elasticity or spring against sudden jerks. With an open rail, the bollards may be placed so close to the gunwale that the mooring line may pass directly over the side, a strong tabular foundation being built for them over the gutter waterway (Fig. 16). If the bollard is not placed close to the gunwale, a **fair-lead** must be provided as a substitute for the mooring pipe fitted in a close bulwark (Fig. 17). Fair-leads are also fitted at the bow and stern, for towing purposes; and when large they are provided with rollers (Fig. 9, Plate 66), to permit of the towing line being hauled in with little friction, however indirect its outboard lead.

Art. 363. The stanchions of an **open rail** (Fig. 5, Plate 59) are of forged iron, stamped under the steam hammer from a stout bar; a hole is drilled in each ball, a loose fit for the rails, which, when passed through, are tightened by wedging and caulking. Stanchions of cast steel, in cruciform section, were tried at one time, but met with little favour. They may be riveted to the top of the sheer strake (Fig. 5) or to the stringer plate (Fig. 6), or they

may be bolted to the waterway plank (Fig. 7); to place them in from the gunwale is advantageous, for they are then less liable to be damaged by contact with other vessels, etc. In passenger steamers a teak-wood rail is usually substituted for the upper rod (Fig. 5), otherwise a tube of large diameter may be employed (see Fig. 17). In vessels having a promenade or shade deck, open at the sides, the rail stanchions are extended upwards to support it; if the deck is light, only alternate ones (see Fig. 17, Plate 59, and Plate 107). These stanchions are often formed of T bars (Fig. 5, Plate 76, and Fig. 5, Plate 67). If forged they must be substantial; their upper ends are provided with a forged palm, usually L-shaped, so that it may take the ends of the promenade-deck beams, and at the same time connect them to the fore-and-aft face plate of the flying deck. Abreast the hatchways, an open rail is formed as a sort of portable gateway, the stanchions fitting in sockets; and similar socket stanchions, with chain rails, are provided on the forecastle deck in way of the anchors, unless these are of self-stowing type. At the front of the bridge deck, in way of the compass, the stanchions and rods are sometimes of brass, to avoid galvanic effects; elsewhere, of course, they are of galvanized iron. Provision must be made for erecting **awning stanchions**; these may be of light tubing, with solid welded ends (see Figs. 7 and 8, Plate 59), the upper parts being suitably formed to support the ends of cross rafters and take the fore-and-aft ridge lines. In passenger vessels portable rails and stanchions are provided around the lower deck hatchways, as a protection for the passengers when these are open; otherwise a portable wood casing (of open sparring) may be fitted from deck to deck.

Art. 364. The weather-deck **hatchways** (Plate 58) are features more or less vulnerable, for when waves break over the ship there is a chance of the covers being displaced, in which case water would pass into the hold, damage cargo, endanger the ship, etc. They are closed by stout wooden shutters, termed "*hatches*," watertightness being secured by spreading over all a tarpaulin, or *hatch cover*, usually two or three, one over the other (see Fig. 17). The margin of the tarpaulin hangs over the coaming, against which it is pressed by flat bars, termed "*hatch battens*," clamped by wedges. The hatches are held down by the tightly stretched tarpaulins; also by flat *locking bars* laid across the top, which are secured at the ends by a padlock, so that there may be no unauthorized entry into the hold.

It is evident that hatchways closed in this way cannot, as regards watertightness and general security, be compared with the surrounding deck surface. In fine weather they may be perfectly secure, but in stormy weather they are a source of anxiety to those on board and are constantly under inspection. It is not an uncommon occurrence for the tarpaulins to be torn by the sea and wind, or by loose deck gear thrown about by the waves. And it sometimes happens that the wood hatches under the tarpaulin are jerked out of place by the concussive effects of falling waves, when, of course, the tarpaulins, being unsupported, may tear and admit water. The fixture of the margin of the tarpaulin is a vulnerable feature. The hatch battens are clamped against the coaming by wooden wedges, which fit in cleats riveted to the coaming (Fig. 17), or by pinching screws (Fig. 22). Wedges present a large surface to the dislodging action of deck water, but, on the other hand, they possess elasticity, which pinching screws do not, and when swollen by the water they do not readily work loose; for this reason they are generally preferred.

As the **hatch battens** are slender, and are not usually perfectly straight, they may not press the covers, everywhere, tightly against the coaming. They should, therefore, be substantial, at least $\frac{3}{8}$ inch thick; and the cleats should be placed at close intervals, not greater than 2 feet.

Sometimes battens of angle section are adopted, which, owing to their greater stiffness, have a better clamping effect. In heavy weather, deck water dashing against the coaming may find its way upwards below the tarpaulins, and, aided by the wind, may even lift them and tear them to pieces. It should be observed that when water in violent movement is suddenly arrested it exerts a pressure on the arresting surface, and possesses leak-searching characteristics precisely similar to those displayed by still water under a hydrostatic head. An excellent hatch-battening arrangement,[1] free in great measure from the above objections, is shown in Fig. 18. Here, instead of a few isolated cleats, a continuous one, in the form of a small Z bar, is riveted to the coaming, which, by forming a trough for the battens, the edges of the tarpaulin and wedges, protects them from water pressure and the dislodging effect of the wind and waves. When the end coaming of a hatchway is formed by a transverse bulkhead or by the end of a deck house (Fig. 10A), special provision must be made for properly fixing the tarpaulins; by forming a channel or trough, into which the margin of the tarpaulin may be turned down, and be tightly battened against the coaming in the usual way.

Art. 365. The **height of the coamings** of weather-deck hatchways is an important matter. In stormy weather the deck may be frequently flooded with water, so that, evidently, when the hatch coamings are high, the covers are less likely to be inundated and subjected to the trying ordeal of preventing its passage below. Formerly 1 foot was the usual height; now 2 feet is more common (Lloyd's rules specify this as a minimum, for ordinary upper and spar decks), but much depends on the character of the deck. In well-deck vessels, for instance, the coaming of the hatchway in the well, where the deck may be constantly covered with water, is often 3 feet high. An awning or bridge deck, on the other hand, stands high above the sea level, and has no bulwark to retain a volume of deck water; here, therefore, a height of $1\frac{1}{2}$ feet may be ample. And similarly with the trunk-deck and turret-deck type of steamer (Plates 111 and 112); in the former the sides of the trunk erection may be regarded as forming a continuous hatch coaming, 7 or 8 feet high, so that, evidently, the coamings proper, around the openings in the trunk deck, may with safety be quite low. The height of the coamings may also be governed by the degree of security of the battening; in American whale-back vessels, for instance, there are no coamings at all, for the hatchways—mere openings in the deck plating—are closed with perfect security and watertightness by bolted plates.

Different **methods of forming the coamings** are shown in Plate 58. Formerly a **fore-and-aft carling** was fitted to support the ends of the half-beams, and the coaming was then superposed (Fig. 5). Now carlings are usually dispensed with, the coaming itself being extended downwards to take its place (Fig. 6). In the case of lower decks, a distinct carling is still sometimes fitted, and the coaming above, if there is one, may be formed of a deep bulb angle (see Figs. 12, 13, and 15). The coaming of lower-deck hatchways is usually shallow, for if high it would interfere with the working of 'tween-deck cargo, and, of course, there is little chance of the hatchways being inundated by deck water. If a lower-deck hatchway is long, a coaming is useful and necessary, because it then forms a powerful fore-and-aft girder, well able to support the ends of the half-beams; in some cases, when only a shallow carling has been fitted, both it and the half-beams have been bent down and broken by the weight of 'tween-deck cargo stowed alongside and on the hatches.

[1] Brown's "*Patent Continuous Hatch Cleat.*"

The pillars which are fitted at the sides of the hatchway may, of course, give most perfect support, but as they are portable, they may not always be in place. Lloyd's rules specify a minimum depth for the carlings or shallow coamings of lower-deck hatchways; it varies from 16 to 20 inches according to the length of the hatchway, and, in view of their shallowness, they require them to be $\frac{1}{20}$ inch thicker than the coamings of upper-deck hatchways. In cases where a coaming, projecting above the deck, might be an impediment in working cargo, it may be arranged to project downwards below the ends of the half-beams, for, of course, when its ends are well secured this does not affect its efficiency as a fore-and-aft beam.

When there are no coamings around a lower-deck hatchway, an angle-bar is usually fitted, to keep back drainage water and receive the ends of the hatches (Fig. 15, Plate 58); and, to protect its vertical flange, a plank of hard wood may be fitted alongside, as shown. In passenger vessels, having cabins and saloons in the 'tween decks, the hatchways on the second deck may be arranged to form, when closed, a flush surface with the surrounding deck, thus providing valuable deck area for the passengers. The tarpaulins are then secured as shown in Fig. 13, by forcing portable wooden chocks or planks into a trough or channel formed around the hatchway, the tarpaulins being below them. Tarpaulins are, of course, necessary here, for the hatchway overhead may be closed only with gratings—for ventilation—and may be provided with a portable skylight or companion-way, through which sea water might pass below. Trunk hatchways, as fitted in passenger vessels, are described in Art. 226.

The coaming plates of weather-deck hatchways are exposed to considerable wear and tear, to blows from cargo in process of hoisting or lowering, or from the waves, or from deck gear thrown adrift in stormy weather, and, if not frequently painted, they are liable to rapid corrosion. They should, therefore, be of substantial thickness. Lloyd's rules specify $\frac{7}{20}$ to $\frac{9}{20}$ inch, according to the length of the hatchway, and as the end coamings have no half-beams to support, they may be $\frac{1}{20}$ inch thinner, but may not be less than $\frac{7}{20}$ inch. The ends of the half-beams are connected to the coaming or carling with angle lugs. When the beams are on alternate frames, Lloyd's rules require two lugs, otherwise a single one suffices, and they require each flange of the lugs to have three rivets when the beam is so deep as $7\frac{1}{2}$ inches (Fig. 7, Plate 58), and four if 10 inches deep (Fig. 6).

Art. 366. The wood hatches must be supported by strong bearers, for they are subject to crushing downward blows from falling waves. If the hatchway is small, less than 12 feet long by 10 feet wide, a single fore-and-aft bearer is placed at the centre; if over 10 feet wide, three are required. If the length of the hatchway exceeds 12 feet, Lloyd's rules require an athwartship beam, termed a "**shifting beam**," of T bulb section, to be fitted at mid-length (see Fig. 5, Plate 58). This forms a support for the **fore-and-afters**, which, being short, need not be so strong; formerly the latter were always of timber, elm, oak, or pitch pine, but now they are very commonly of steel, as shown in Figs. 8 and 23. When the length of the hatchway exceeds 16 feet, the athwartship beam becomes a deep **web plate** (Figs. 6 to 9 and 23) of the same depth and thickness as the coaming; it is lightened with holes, and is stiffened with double angles or double half-round mouldings on its upper and lower edges (Fig. 1, Plate 57). If the length exceeds 20 feet, two web beams are fitted (Plate 109). In many recent vessels fore-and-afters are dispensed with altogether, the athwartship web plates being fitted close together, at intervals of about 5 feet, and the hatches placed fore and aft between them.

The portable hatch beams or webs are secured between double vertical angles, riveted to the coaming, forming a groove for the end of the plate, and permitting of a bolt attachment, as shown in Fig. 7, Plate 58. Together with the support which the web beams afford to the fore-and-afters and hatches, they have considerable structural capabilities, for when securely bolted they make good the transverse strength lost by the absence of through deck beams. In practice, however, their capabilities in this respect are frequently nullified by the circumstance that they are often improperly bolted; very commonly only one out of six or seven bolts is put in place, or none at all if the angle lugs are closed at the bottom so as to sustain the beam, and in many cases the lugs become cracked or broken. When this is so, the beam serves merely as a strut; it is of no use as a tie. Sometimes, to avoid the above, a sort of dovetail groove is substituted for the double-angle attachment, formed of a steel casting (B, Fig. 14), or a dished steel plate (A, Fig. 14). It is evident that the shallow cross beam shown in Fig. 5 is of little service in the above respects, for it is secured only to the yielding upper part of the coaming; in order that it may tie the severed half-beams, it should have a knee at either end, or a knee may be fitted on the outside of the coaming, as shown in Fig. 1, Plate 57. When loading or discharging cargo, the portable hatch beams are usually removed; but not always, in which case the angles upon the upper and lower edges are apt to be bent and broken; they should, therefore, be substantial, or large, double, half-round mouldings may be substituted.

Similar web beams and fore-and-afters are provided for the hatchways of lower decks. If the hatchway is wide and the side coamings shallow, the cross beams take the form shown in Fig. 11, Plate 58, for if they were shallow throughout they might be too weak; in such cases Lloyd's rules require the depth of the beam at the middle to be 25 per cent. greater than at the ends. Failure of the portable beams of lower-deck hatchways was formerly not uncommon; it occurred as a result of heavy weather, when the vertical movement of the ship caused a large virtual increase in the weight of the cargo stowed on the top of the hatches. When the hatchways are wider than they are long, which, in modern vessels of broad beam, is very commonly the case, the portable beams may be placed fore-and-aft, for, having a shorter span, they are then stronger and more capable. When the same homogeneous cargo is stowed in both the hold and 'tween decks, the lower-deck hatches are not always closed, in which case the cargo in the 'tween decks simply rests on that in the hold below. The hatch coamings may have **rounded or square corners** (Fig. 23). As regards the closing of the hatchway, round corners are less convenient than square, for the hatch battens do not clamp the tarpaulins so well, and special corner hatches are required; for this reason, therefore, square corners are usually preferred. In discharging cargo stowed remote from the hatchway, it must, in the first place, be hauled along laterally. This is done by attaching thereto the hoisting line of the derrick, which, rubbing with force against the lower edge of the coaming plate, may not only suffer itself, but, if it be a chain, may injure the edge of the coaming. This may be obviated by curving the lower edge of the coaming as shown in Figs. 8 and 12, or by fitting a half-round moulding to take the chafe (Figs. 7 and 9).

The upper edge of the coaming must be stiffened and rounded off to avoid cutting the tarpaulins, and a suitable ledge ($1\frac{3}{4}$ inch wide) must be provided for the ends of the hatches. This may be done by riveting a half-round moulding on the outside, usually of hollow section, and a ledge within (Fig. 17, Plate 58), or by employing a single bar of a section appropriate

to both purposes (see Figs. 16 and 18). It is important that the inner surface of the coaming should be free from projections, so that cargo in process of hoisting or lowering may not catch. The **hatch moulding** shown in Fig. 18 dispenses with a projecting ledge, and, being a single part, is more easily fitted. As the hatches usually lie athwartship, a ledge is not required on the end coaming. Sockets are riveted to the coaming to support the ends of the fore-and-afters; they may be of steel or iron, wrought or cast, and they should be sufficiently substantial to withstand blows from cargo (Figs. 3 and 4). If the fore-and-afters are of timber, a short plate should be fitted at their ends (Fig. 3), on their lower surface; for as the supporting sockets are shallow—to minimize their obstructive effect—the wood is subject to such local pressure that it is apt to crush and wear away, when, of course, there is a danger of its slipping past the socket. Lloyd's rules require that the sockets shall be sufficiently deep to give at least 2 inches bearing for the fore-and-afters.

Formerly the **wood hatches** were built of thin boards, with connecting grounds or cross pieces below. Now they are always of solid timber (Figs. 5 and 23, Plate 58), $2\frac{1}{2}$ or 3 inches thick, formed by tie-bolting two 12-inch planks of white or red pine. They are subject to particularly rough usage during loading and discharging operations, so that they soon split and break up. They have, therefore, to be frequently overhauled, for if their surface, when all are in place, should contain holes and wide crevices, the tarpaulins, when subjected to sea pressure, might tear and admit water; and, further, when their edges are worn, they are more readily dislodged by shocks from the waves. In passenger vessels and those in the fruit trade, which require ample ventilation, supplementary, grated hatches are usually provided. Small hatchways are sometimes covered with a "booby-hatch." This is simply a teak-wood cover, having a sliding shutter to act as a companion-way. The after hatchway in sailing-ships is often covered in this way.

Art. 367. Deep ballast tanks, which are intended also to serve for cargo, must have **watertight hatchways** (Figs. 1 to 4, Plate 71). Two comparatively small ones are usually provided, one on either side of the longitudinal wash bulkhead (Figs. 4 and 5, Plate 24), close together, so as to fall below the single hatchway of the deck above; if a single large central one were provided, the watertight cover would be very unwieldy. The cover is in one piece, formed usually of a single large plate; if in two, there would be a cross joint, difficult to make watertight. The watertight joint with the coaming may be made in different ways, as shown in Figs. 1 to 4, Plate 71. If rubber strips are used they should be secured at *both* edges, for rubber is apt to stick to the coaming and tear when the cover is lifted (see B, Fig. 2, Plate 71, and Figs. 7 and 11, Plate 72). On account of the cost and perishable nature of rubber, and the rather extensive fitting work involved in its fixture, it is usually preferred to secure a watertight joint by means of putty and rope yarn, placed between the cover and an angle bar fitted on the edge of the coaming (Fig. 2, Plate 71); or specially prepared packing may be inserted in a groove in the cover or coaming, as shown in Fig. 1, A Fig. 2, and Fig. 3. The coaming should be 18 or 24 inches high, so that the space within the hatchway may be sufficiently large to act as a feeder, and thus ensure the tank proper being always quite full of water. It is sometimes formed of a large bulb-angle bar, but this does not secure the above advantage. A coaming plate should, of course, be stiffened at, or near, the edge with an angle bar, so that it may resist blows from cargo and pressure from the water contained in the tank. The cover should be stiffened with cross bars, disposed parallel to the shortest edge,

and they should be tapered at their ends, so as to relieve the terminal connecting rivets of undue stress. The plate itself should be thick, for it is exposed to rough usage, and it should be stiffened around its edge with an angle frame or doubling strip, so as to distribute the clamping pressure of the bolts. Sometimes it is made of cast steel, but it is then very heavy and cumbrous. It is well to provide a stud bolt in the cover, by removing which, the height of the water, when the tank is nearly full, may be readily ascertained; and a manhole may also be provided, to give ready access to the tank. The securing bolts may be linked, or pivoted, to eye plates or lugs riveted on the coaming; or they may pass through an angle bar on the coaming (see Figs. 1, 2, and 3). The lower decks of warships usually act as watertight divisions, so that all hatchways are of watertight type; and as they are not subject to the wear and tear due to loading and discharging cargo, lightness and strength are the governing features in their design; their lids are hinged, and the bolts are provided with brass **turnbuckles** instead of nuts, so that they may be hove up quickly by hand (see Fig. 11, Plate 72).

Art. 368. In **vessels designed for the coasting coal trade**, it is desirable that the hatchways should be large (Fig. 7, Plate 8), so that when the coal is shot through them it may fill the holds sufficiently full to sink the vessel to her load line without the necessity for laborious hand trimming. It should be observed that coal (light North-country coal) requires for each ton weight a space of about 44 cubic feet, and as vessels designed for the coal trade can usually carry at load draught a weight of cargo—in tons—equal to the total hold space in units of about 51 cubic feet, the space which of necessity remains vacant is only about one-seventh of the whole. In order, therefore, to dispense with hand trimming, the hatchways should be so large that the coal, when merely shot through them, may fill at least six-sevenths of the total hold space, for if not the vessel would not, in the absence of hand trimming, be fully loaded, *i.e.* she would not be brought down to her load line.

A heap of coal will retain its form unless the inclination of its sides is steeper than about 35 degrees—the "limiting angle of repose." It follows, therefore, that unless the coal shot through the hatchways is trimmed laterally, there must exist vacant spaces, triangular in section, in the "wings," *i.e.* under the deck at the sides of the hatchways; also, it is evident that the wider the hatchways the smaller these spaces will become. Very wide **"self trimming" hatchways** tend to injure the strength of the hull, owing to the removal of so much deck plating, and, at the same time, the extensiveness of the vulnerable hatch covers may prejudice the vessel's safety in stormy weather at sea. These objections are met by increasing the strength of the deck at the sides of the hatchway, and of the coaming plates, and by raising the latter high above the deck, so that the covers may not be inundated by deck water. At one time it was common to slope the coamings inwards, so as to reduce the area of the hatch covers,[1] as shown in Fig. 2 and 3, Plate 57. It will be observed that the coaming is here really a portion of the deck inclined upwards, for the beams are extended to its upper edge.

As just seen, there must exist—in the absence of hand-trimming—empty spaces in the wings. Now, in loading a vessel, it would evidently be improper to permit the coal to retain its natural angle of repose, for with the rolling of the ship it would slip downwards, and in heavy weather the tossing and jerking might cause the whole mass to move to one side

[1] Price's "*Patent Self-trimming Hatchway.*" See Mr. Denton's paper, *Trans. Institution of Naval Architects*, 1875.

and perhaps give the vessel a dangerous list. To avoid this, therefore, when self-trimming hatchways are adopted or hand trimming is dispensed with, **wing boards** are fitted, so as permanently to shut off the vacant spaces under the gunwale (Figs. 1 and 2, Plate 57). With the exceedingly long hatchways sometimes adopted in this class of vessel, the transverse strength may be maintained by fitting, in association with web frames, a few powerful through beams, which, of course, as regards the stowage of coal cargoes, are not obstructive; and they may be provided with substantial joints, so that should it be required at any time to stow a large mass—perhaps long girders or machinery—they may be temporarily removed. In small vessels, having very large hatchways, the coamings become important structural parts, and in order that they may contribute useful longitudinal and transverse strength to the hull, their continuity should be studied, and when very deep they should be held erect by bracket plates to the deck (see Fig. 1). Coal does not settle, and when properly stowed is not liable to shift like grain, so that here neither feeders nor centre-line shifting boards are required.

Art. 369. As a supplementary means of working cargo, **small cargo ports** are sometimes cut in the vessel's sides in the 'tween decks, through which packages of small section may be discharged or loaded by hand (see Fig. 1, Plate 60). They are only provided in large vessels, for in small they would be too near the waterline, and might lie below the level of the quay. As the working of the cargo through these ports and through the hatchways may be carried on simultaneously, they should be placed clear of one another, so that there may be no interference in the landing of the goods. The ports are small, 2 or $2\frac{1}{2}$ feet square, for to make them large would sacrifice important structural strength, and as it is only small packages that can be conveniently dealt with by hand, a comparatively small opening is sufficient. In the case of a bridge-deck side, or that of a shelter or awning-deck erection, **cargo or cattle doors** of large size (Figs. 2 and 4) are often provided, for here the side is of comparatively light construction, and so is of less structural value. But in large vessels, where longitudinal strength is important and might be prejudiced by the doors, ample compensation must be introduced in way of the ports; longitudinally, by doubling the shell plating above and below, and perhaps the deck stringer as well, and transversely (if frames are severed) by fitting web plates on the adjacent frames. To stiffen the free edge of the shell plating, an angle frame is fitted around the opening. Such compensation is, of course, particularly necessary in those ports which are situated towards 'midships and clear of the bridge-deck side plating; and in these care should be observed that they do not fall below or over the end joints of the sheer strakes, or in any other line of relative weakness, such as the termination of bridge or bulwark plating.

Small cargo ports may be closed like the coaling ports described in Art. 236, by tap bolts hove up from the outside (Fig. 3, Plate 60), but more usually strong backs or buckler bars are employed, which, of course, are hove up from within (Fig. 1). A watertight joint is usually obtained by putty and spunyarn; otherwise, indiarubber may be employed, as shown at R, Fig. 1. It should be observed that to permit of the door being pressed home on its bed in way of the hinges, the pin holes in one part of the latter should be slightly oval. The door itself is usually stiffened by fitting around it an angle frame; otherwise, it may be made of extra thick plating, stiffened by one or two cross bars. The large cargo doors in the side of a bridge house are very commonly in two parts, an upper and a lower, so that while the upper one is opened at sea, for light

and ventilation, the lower one forms a bulwark. In passenger vessels, or those carrying cattle, iron gratings are provided for use in fine weather.

Wood ships are very commonly employed in the timber trade, and to permit of long logs being loaded or discharged endwise, into or from the hold, a **bow-port** is usually provided close to the stem, sometimes one for the 'tween decks and one for the hold. Similar ports are sometimes provided in iron ships, but as in these there is a collision bulkhead, they involve the undesirable feature of a detachable bulkhead plate (Art. 407), through which to pass the logs. As bow-ports are particularly exposed to blows from the waves, they should be securely fastened by tap-bolts, hove up from the outside through a double thickness of plating; internal strong backs might be loosened by the continuous jarring. And care should be observed that the strength and stiffness of the vessel's bow is not prejudiced by the port, web frames or stringers being introduced to make good the transverse strength lost by the cutting of frames, etc.

Art. 370. An important feature of a modern cargo vessel is the facilities for rapidly **loading and discharging cargo** from the various holds and 'tween decks (see Plates 61 and 109,). Their adequacy depends on the size and number of the hatchways, on the sufficiency of the lifting appliances, the derricks and winches, and on the structural design of the ship. The cargo situated directly under a hatchway may be lifted and swung overboard with expedition; that not directly under must first be transported laterally, and it is evident that to minimize the labour and time involved, the hatchways should be numerous and large. Formerly, expedition in loading and discharging was not so urgent, for freights were usually so high as to ensure, in any case, a good profit; now despatch and economy are often essential to commercial success, and, accordingly in modern vessels the hatchways are usually numerous and of large size, and the means of working the cargo elaborate and extensive. In vessels of moderate beam, hatchways 26 feet long by 16 feet broad are common; and in vessels of large beam, hatchways 18 feet long by 24 feet wide are not unusual. Width is advantageous in minimizing the distance of the hatchway from the vessel's side, so that the shore cranes—often of limited outreach—may plumb the hatchway; also, in permitting of discharging operations being conducted simultaneously on both sides of the ship. In some cases, the better to secure these advantages, instead of one central hatchway, two are provided, one to port and one to starboard, just clear of the deck stringer. This is a common arrangement in passenger vessels having large central deck houses or cabin spaces, and which, being employed in foreign coasting trade, where the cargo is discharged into lighters, require special facilities for working it.

The arrangement of **derricks and winches** varies greatly (see Figs. 9 to 12, Plate 61). In some regular liners deck machinery may seldom be required, for efficient hydraulic cranes may be available at their own special loading and discharging berths. In practice, however, all steamers are provided with steam winches; in large modern cargo vessels there are usually two to each large hatchway. Modern sailing-ships are usually provided with a steam winch, which serves not only for working cargo, but for warping the ship, working the windlass and pumps by messenger chain, and for a purchase for the halyards and other heavy hauling work; as a rule, however, it is never used at sea. It and its donkey boiler are placed together in the 'midship deck house, the warping ends of the winch projecting on either side; sometimes, however, a small donkey boiler and winch are provided, fixed together on a bogey so that they may be transported to any particular hatchway. Sailing-ships are generally loaded and discharged

by shore cranes, or, if these are not available, by hand winches, one of which is usually placed at each hatchway, the lifting lines being suspended from the yards or stays. They may lie in port for long periods, a source of loss which in their case is less important than in steamers, owing to their smaller first cost and working expenses.

Art. 371. Ordinary **derricks** are of pitch pine or spruce, and are usually capable of lifting a load of about five tons weight. When specially heavy weights must be lifted they are made of steel, like a yard, and they may be pivoted on the deck in front of the mast, as in Fig. 1, Plate 61. An efficient derrick should be capable of lifting a large package from the hatchway, and of swinging it quite clear of the vessel's side, on to the quay; if it can only deposit the package on deck, supplementary lifting gear and double handling become necessary. Its outreach might, of course, be increased by lowering its head, in the manner of a land crane, but—excepting hydraulic derricks—this is practically never done; its head stay is of fixed length (Fig. 6), to make it a running tackle, or "*topping lift*," would complicate the operations. Derricks may be pivoted and stayed from the mast, or from special **derrick posts**, placed anywhere on the deck. Formerly only mast derricks were used, but in modern vessels of great beam, if the mast is near the hatchways and the derrick plumbs the centre thereof, it might not be capable of swinging a large package overboard or sufficiently clear of the side (see Fig. 12). By providing special derrick posts, on either side of the hatchway, the necessary conditions may be readily satisfied, and by a comparatively short derrick (Figs. 10 and 11). A similar result may sometimes be secured without a derrick post, by pivoting the derrick on the deck alongside of the mast, and leading its head stay to the end of a horizontal bar, fixed and stayed aloft on the mast, and projecting therefrom over the heel of the derrick.

It is desirable for the **proper working of a derrick** that the point of fixture of its head stay should be over, or nearly over, its heel pivot, for if much to one side the derrick would constantly swing towards that side; this circumstance, however, is commonly taken advantage of, the upper end of the stay being fixed slightly to port or starboard, so that the derrick may swing overboard of its own accord, a single guy towards the other side being sufficient to pull it back over the hatchway. The rake of a mast, and the fixture, on the vessel's side abaft it, of the shrouds and backstays, detracts from its efficiency as a derrick post. To obviate the effect of the rake, a projecting structure is commonly built on the mast to take the heels of the derricks, in such position that they may be nearly plumb with the ends of their stays above. In some modern steamers the main purpose of the masts is to serve as derrick posts; and, to increase their capabilities in this respect, they are sometimes fitted quite plumb, without rake. For lifting very heavy, bulky masses, a mast derrick is superior to one swung from a post, for it may be pivoted high above the deck, and be of great length, so as to give ample drift; and as its head stay, fixed to the lofty mast, may leave it horizontally, or with an upward inclination, it may neither suffer undue tension nor convey undue compressive stress to the derrick. To secure the same conditions with a derrick post, one of great length is required. Sometimes mast derricks are stayed horizontally from the mast, at a point high above the deck, and as in such cases the thrust of the derrick may cause severe local stress on the mast, this should be specially strengthened. Steam cranes are sometimes adopted in coasting vessels as a substitute for derricks and winches; they are advantageous in that they may be placed anywhere on the deck, and may be readily worked, for they contain their own hoisting and slewing gear.

Derrick posts (Figs. 4, 5, and 6, Plate 61) which are designed to withstand, without stays, the whole pull of the derrick, must be strongly constructed. They are usually from 15 to 20 inches diameter, of plating about $\frac{1}{2}$ inch thick at the deck to $\frac{3}{8}$ inch at the top. When stayed they may be considerably thinner. They usually pass down to the second deck (Fig. 4); if secured to the upper deck only, side bracket plates are fitted, and the beams and deck plating below suitably strengthened. In many cases the end of a deck erection serves as a convenient support (Fig. 5). A high-class derrick post and gear is shown in Fig. 6. Derrick posts also serve the useful purpose of ventilators for the hold and 'tween deck; this, indeed, being often an object in fitting them (Art. 442).

The disposition of the **winches** with regard to the derricks is an important matter (see Figs. 9 to 12, Plate 61). The hoisting or whipping line should pass from the leading block of the derrick, square to the winding barrel or whipping drum of the winch; for if not a special arrangement of leading blocks becomes necessary. In the case of mast derricks, if there is a single winch, it is, of course, placed at the centre line; if there are two, and if the derricks are close together, then, to secure a fair lead to both, they are sometimes disposed at an angle (Fig. 9). The necessary effect, however, is often secured by placing the two derricks remote transversely from each other, providing, for the purpose, a projecting structure on the mast (Figs. 7, 8, and 12). When derrick posts are adopted, the winches may be disposed in whatever manner is most suitable (Figs. 10 and 11); very commonly, while the winches are placed close together, out of the way at the end of a hatchway, their main spindle is extended outwards (usually by means of a portable extension piece) towards the derrick post (Fig. 10), and is provided with a large whipping drum, suitable for continuous and quick winding.

In an ordinary steam winch the cylinders are small, the necessary power being secured by toothed-wheel gearing. The gain in power by gearing is, of course, accompanied by a loss of speed in the lift, and to maintain this, therefore, the engine is driven at high speed, with the result that there is much noise and vibration. In passenger vessels, ordinary steam winches are, consequently, a source of great discomfort. In some high-class vessels, not having hydraulic gear, a special type of steam winch is employed, designed to run without noise and vibration. This is accomplished by dispensing with all gearing, the necessary power being secured by extra large cylinders of oscillating type, geared direct to large cranks on the main spindle. As there is thus a minimum number of moving parts,—no connecting rods or pinion wheels—and as the piston speed is small, the winch works steadily and comparatively noiselessly.

Art. 372. In high-class passenger vessels **hydraulic derricks** or cranes are now often employed as a substitute for steam winches.[1] A hydraulic derrick carries, fixed upon itself, all the necessary mechanism (hydraulic rams, pulleys, and chains), not only for lifting the load, but for slewing it from side to side, and altering the hoist or inclination so as to vary the outreach. They are superior to steam winches, in that they work with great expedition, noiselessly, and without vibration; they occupy no deck space, they require no hot steam pipes (which cause a considerable loss of power by condensation), but are operated by a couple of small water pipes, which, being cold, may be led along anywhere in the 'tween decks instead of on the upper deck, where exposed to the weather. In vessels carrying passengers, the absence of noise and vibration is, of course, a most

[1] For a description of hydraulic deck machinery, see Mr. Brown's papers, *Trans. Institution of Naval Architects*, 1883 and 1890.

important matter. In cargo vessels, hydraulic deck machinery is not often employed, on account of its greater first cost. It tends to greater efficiency in working, however, for instead of numerous self-contained motors there is only one, a steam pump in the engine room. This stores its energy in an accumulator, which, instead of the usual heavy weight lifted against gravity (inapplicable in a ship subject to vertical and other movements), is a piston forced against a constant pressure of steam. As a substitute for the ordinary winches and derricks, hydraulic derricks or cranes are less convenient in that, as they cannot be used for warping purposes, it is necessary to provide special warping capstans—hydraulic or steam. In some cases, therefore, when hydraulic power is adopted, it is preferred to apply it to ordinary winches.

The ingenious device, known as the "**Temperly Transporter,**"[1] is now largely employed in the loading and discharging of large vessels. When swung over a hatchway, packages may be lifted from the hold, run out on the transporter, and lowered down on to the quay, with the greatest expedition, all movements being controlled by merely hauling in or slacking off a single line.

Art. 373. When a **winch** sits on a wood deck, there may be laid for its reception a **doubling or sole** of teak wood, 2 or 3 inches thick; this increases the rigidity of its foundation, distributes the pulling and vibrating effects, and protects the deck against decay, which, owing to the heat and dirty, oily moisture, is here often particularly rapid. In high-class passenger vessels provision is made for draining away dirty, oily water, by leading scupper pipes (from a gutter provided around the sole plate of the winch) below the deck and through the vessel's side. If the deck is not plated, local plating is provided to take the holding-down bolts; otherwise, thick chocks of timber must be fitted between the beams. A winch in violent movement tends to produce excessive drum-like vibration of the deck, to obviate which, the latter should be well pillared, and thickened or stiffened to deprive it of its flexible or drum-like character: sometimes, when insufficiently pillared, the vibration is so intense as to loosen or break the rivets of the pillar heads. A wood deck under a steam winch is very apt to decay, and it is now usual, therefore, when a plated deck is sheathed with wood, to leave uncovered the portions below the winches, the planks abutting on a marginal angle bar riveted to the plating. The winch might then sit directly on the plating, but it is usual to rivet to the latter **bearers**, of Z or channel bar (Fig. 9, Plate 61, and Fig. 4, Plate 86); for then, as no bolts pass through the deck, there is no chance of leakage, the deck is well stiffened, and the vibrating and pulling effects of the winch are well distributed. When so arranged, the deck plating below the winch is generally covered with cement. In the case of an unsheathed plated deck, a similar plan is adopted, *i.e.* fore-and-aft bearers are provided to stiffen the deck and take the winch bolts.

Art. 374. The **steam pipes** for the winches, windlass, and steering gear are led along the upper deck by the sides of the hatchways. Formerly, the exhaust steam was passed overboard, by a pipe led across the deck at each winch; now, it is common to return it, by a special pipe, to a condenser tank in the engine room, thus saving fresh water, avoiding the confusion and disturbance on deck caused by the blinding clouds of vapour and the noise of the escaping steam, and at the same time avoiding the chance of damaging goods lying on the quay or in barges alongside. The steam pipes are raised a few inches from the deck, being held in place by

[1] A description and illustration of this apparatus will be found in *Engineering* for May 11, 1900.

chairs, of wrought iron, cast iron, or steel (Figs. 11 to 14, Plate 69); and, to protect them, plate covers are bolted to the chairs or to an angle bar riveted to the hatch coaming or casing. In heavy weather the pipes are particularly exposed to damage; not infrequently a wave, sweeping the deck, may carry away the covers and break the chairs and pipes—a serious matter in the case of steam pipes to the steering gear. To avoid this, the plate covers and chairs should be very substantial, and the former should be turned down (more particularly alongside of the hatchways), so that the water, not having free access below, may not exert so great a lifting or dislodging force. And all bolts connecting the chairs and covers to the deck should be tapped through the plating and have nuts on their points below. The covers are usually of chequered plating, about $\frac{1}{4}$ inch thick; but sometimes they are of cast iron, in trough-section segments, forming an enclosed conduit for the pipes. In some cases, instead of plate covers, fore-and-aft iron bars are fitted over the pipes (Fig. 12); as these form a sort of open sparring, they offer little surface to the disruptive action of deck water, but they also afford less protection to the pipes; where there is only one pipe it is sometimes protected with an angle-bar cover. In some cases the pipes are led along below the deck, but this cannot be done when the 'tween deck is a cargo space, because of the heat and the chance of the pipes becoming defective and leaky.

CHAPTER XXVI.

Art. 375. The construction of the **masts** and the arrangement of the **rigging** of sailing-ships was formerly a subject of much careful thought; and, aided by continuous experience, the current practice at any particular period has generally been satisfactory. About the year 1874, however, a new class of sailing-ship, about double the size of those formerly built, came into vogue; and it was soon observed that although the masts and rigging were apparently well proportioned, they were much less trustworthy than those of the earlier vessels. Attention was particularly directed to the circumstance by the dismasting of a number of new ships while on their first voyage; and, accordingly, Lloyd's Register instituted an investigation, the results of which were embodied in a report drawn up by the Chief Surveyor and his assistants.[1] In the following, some of the more important conclusions of this report will be noticed.

One of the principle causes of the **dismasting** of these large vessels was their great stiffness: in smaller ships an excessive pressure of wind made itself evident by an excessive heel, which at once called for a reduction of sail; but the new vessels were so broad and stable (their stability was often excessive on account of improper loading) that a pressure of wind, excessive as regards the masts and rigging, did not proclaim itself in the usual way, by heeling the ship, and it was on account of the absence of such premonitory heeling that the masts were sometimes unduly pressed with sail. Subsequently, great improvements were made in the rigging, by the substitution of steel-wire for iron-wire ropes, and of *rigging screws* for tightening the shrouds, etc., in place of the old-fashioned *dead-eyes* and *hemp lanyards* (Figs. 7 and 8, Plate 64, and Plate 100). And, further, the adoption, in large vessels, of four masts instead of three (see Fig. 1, Plate 62, and Plate 63), greatly reduced the stresses on the masts and rigging; for, of course, with the same total area of sail, each of the four masts has a smaller proportion to support. In some large, modern sailing-ships this principle has been carried still further, by the adoption of five masts.

The masts are subject to three distinct bending forces. One of these is, of course, the wind pressure on the sails. Another is that brought about by the rolling and pitching movement of the ship, which, by causing the masts to sway from side to side, has an effect identical to what may be observed if a slender wand is used as a switch—if whipped smartly backwards and forwards it will snap. The third bending force is that due to the top-weight of the masts, yards, and sails, which, when the vessel inclines to leewards, assists the wind in bending over the masts.

The **capabilities of the masts and rigging** in resisting these forces are dependent on numerous circumstances. In ordinary cases, a modern ship would be forced over on her beam ends or capsized before the masts

[1] "*Report on Masting.*" Published in book form by *Lloyd's Register.*

gave way; *i.e.* the moment of resistance of the masts and rigging is greater than the vessel's righting moment, or moment of stability. Here the strength of the masts would appear to be ample, yet if the same vessel were so loaded as to be excessively stiff, a sudden squall might carry away the masts; and with greater likelihood if it struck her while she rolled to windward, for the motion of the sails against the wind would increase its force. Excessive stiffness, with its consequent violent and jerky rolling, may, in itself, cause the loss of the masts.

In cases of dismasting the masts do not all go at once, but first one, and, as a result of this, the others. In many cases, partial or complete dismasting has resulted from the failure of a comparatively insignificant part. Thus, in one case the failure of the sheet-hoop on the fore mast was followed by the loss of the fore-topgallant mast, and, subsequently, by all the spars excepting the main and mizzen lower masts. In another, the failure of an eye plate for the jib-boom guys was followed by the total loss of all the masts; first the jib-boom gave way when deprived of the support of its stay; then the fore-topgallant mast, stayed to the jib-boom, and so on, the lower masts finally falling aft on deck, due to their fore-and-aft stays being cut by the swinging about of the yards. This curious process of gradual disintegration shows the necessity of providing ample strength in every part, however subsidiary; and of the utmost care in the smith-work of the various mast mountings and rigging attachments—caps, hoops, eye-plates, chains, shackles, etc.

When subjected to a bending force, a mast must deflect slightly before it can give substantial resistance, and the greater the deflection, the greater its resistance. So, also, with the windward rigging; it must stretch before it can offer resistance, and the greater the stretch, the greater its resistance. The *combined* resistance offered by the masts and rigging to a side-bending force depends, therefore, on the efficiency of their co-operation. Theoretically, the full combined strength can only be secured when the co-operation is perfect; *i.e.* when the tautness and inextensibility of the rigging is such that the deflection of the mast, say, when at the breaking point, stretches the rigging to such an extent that it also is just on the point of breaking. If, on account of imperfect co-operation, the mast failed before the rigging, then, of course, much of the strength of the latter might never be called into play; and if its full strength were much greater than that of the mast, the loss of resisting power, due to the premature failure of the latter, might be very great. As usually constructed, the strength of a mast of a large ship is not probably more than about one-seventh that of its rigging (on the windward side); and if the latter were so elastic or extensible that, when the mast was bent to the breaking point, it (the rigging) exerted only one-half its full strength, then the total resistance would be little more than half of the maximum, or what could be offered if both the mast and rigging contributed their full power.

It is evident that only a trifling loss of strength would occur if the above conditions were reversed, *i.e.* if the rigging were strained to destruction before the masts; for although a portion of the strength of the mast would not be called into play, still, as its actual strength is probably less than one-eighth of the whole, the loss would be trifling. Perfect co-operation of the masts and rigging is, of course, unattainable; but this is evidently unimportant so long as the discrepancy is such that the rigging suffers the higher stress. In modern ships this desirable condition is secured, for by the use of steel-wire rigging and rigging screws (in place of the old-fashioned iron-wire rigging and hemp lanyards) the shrouds, etc., are rendered so inextensible that a small deflection of the mast at once

subjects them to a stress greater in proportion to their strength than that experienced by the material of the mast itself. Formerly, this was not so; for, owing to the use of hemp lanyards, the rigging stretched so readily that when the mast was deflected and strained to the breaking point, it (the rigging) only contributed about half the resistance it was capable of giving. That this was so was proved by the fact that in cases of dismasting it was always the masts which broke first, and not the rigging. The above refers, of course, to iron masts; with wood masts different conditions prevail, for they are much more flexible. The loss of efficiency due to lanyards is shown clearly by the following experiment.[1] In the case of a $5\frac{1}{4}$-inch iron-wire shroud, set up by a $5\frac{3}{4}$-inch hemp lanyard, in six parts, the strength of the wire, and that of the six hemp ropes, was found to be practically the same; but while the wire rope (when 17 feet long) stretched 0·87 inches, the corresponding stretch of the lanyard (when 28 inches long between dead-eyes) was as great as 1·98 inches; that is to say, although the length of the lanyard portion of the shroud was only about one tenth of the total length, its stretch was more than double that of the remaining nine-tenths. It is evident, therefore, that, by substituting rigging screws for hemp lanyards, the extensibility of such a shroud would at once be reduced by about two-thirds.

Rigging screws are advantageous not only in producing very inextensible rigging, but in the facility with which it may be set up, so as to be always perfectly taut. **Lanyards** not only stretch—especially when new—but they cannot be set up at sea, unless in fine weather; and, consequently, a continuance of heavy weather, by causing more and more stretching of the rigging, may involve a serious loss of support to the masts; in the earlier vessels this was a common cause of dismasting. There is a danger with rigging screws that the ease with which they may be set up may lead to an unfair initial stress being imposed on certain parts of the rigging, but this is a kind of carelessness that may be easily avoided; the stress should not exceed that necessary to secure simple tautness, and rather more tautness in the lower rigging than in the upper. Sometimes it is still preferred to use lanyards, but in such cases they are of steel-wire rope, and are, therefore, as inextensible as the rigging itself.

The capabilities of the **rigging** in supporting the masts increases with its **spread**; the greater the spread, the larger the angle it makes with the mast, and so the more direct and effective its support. If the shrouds, for instance, met the mast at right angles, a deflection at the hounds (the point of attachment of the shrouds) of, say, 6 inches would also cause 6 inches of stretch in the shrouds. In practice, the inclination is usually such that a deflection of the mast of, say, 6 inches would only cause about 2 inches of stretch in the shrouds; and so it is evident that any slackness or elasticity in the latter might be fatal to their supporting power. Apart, however, from its effect on the relative strainings of the shrouds and mast, the spread of the shrouds has a commanding influence on their transverse staying or supporting power. This, of course, is dependent not merely on their degree of tension, but on how much of it acts transversely on the mast head. If they were horizontal, then, of course, their whole pull would be in operation in resisting deflection of the mast; and in the other extreme, if they were parallel to the mast, none of it would act horizontally, it would all be lost in producing a downward crushing or compressive stress on the mast. Between these two extremes the tension or pull of the shrouds produces simultaneously both effects, a useful horizontal pull, and a useless

[1] "*Report on Masting.*"

downward compressive one; an increase in the spread increasing the former and diminishing the latter.[1]

The increased supporting effect due to large spread in the rigging was recognized from the earliest period; in wood ships, and in the earlier iron vessels, a maximum of spread was secured by passing the rigging outside the bulwark, over projecting platforms, termed "*channels*" (see Fig. 16, Plate 64). In iron vessels, however, this practice was soon given up, for in these the rigging could be firmly secured within the bulwark to the upper part of the stout sheer strake; but, of course, as the smaller spread reduced the supporting power of the rigging, it necessitated stronger or more numerous shrouds. The ends of the shrouds are connected to chain plates, riveted to the sheer strake as shown in Plate 100. These should be very strong, and be attached by at least four good rivets; for, being fixtures, it is desirable that their strength should be in excess of that of the attached shrouds. In sailing-ships, each shroud is passed round the mast (above the cheek plates), and then down again on the same side to form another shroud (Fig. 5, Plate 65). In steamers they may be shackled each one to a separate eye-plate, riveted to the mast, or be secured as in Fig. 7. The fore-and-aft stays of the lower masts are connected to eye, or stay-plates riveted to the deck plating, or bolted through wood chocks fitted between the beams; and in sailing-ships, to give greater strength against the upward pull of the stays, diagonal bars are sometimes fitted below, in the 'tween decks, which may be regarded as a continuation of the stays, giving an additional "anchorage" to the second deck.

It should be observed that the capabilities of the rigging in supporting the masts are greatly affected by the **direction of the wind** and by the simultaneous rolling and pitching movement of the hull. There are four directions producing distinct effects. (1) When the wind is directly ahead, only the fore-and-aft stays give support to the masts; but their supporting effect is very perfect, because of their great spread. (2) With the wind directly astern, support is only given by the backstays and aftermost shrouds, on both sides of the ship. (3) When directly abeam, all of the rigging on the windward side assists. (4) When on the quarter, *i.e.* half-way between the beam and the stern, only the backstays and aftermost shrouds on the windward side assist in the support of the mast. In the *Report on Masting* already cited, the combined strength of the mast and rigging was investigated for these four conditions, for a ship of 1600 tons having rigging set up with lanyards. Assuming the resistance given in No. 1 condition to be unity, the others were respectively 0·75, 0·58, and 0·40. The most trying wind is, therefore, one from the quarter, against which only the windward backstays and aftermost shrouds give support. That these parts do suffer disproportionate stress is frequently observed; for, as a result of heavy weather, while the other rigging may show no signs of having been severely strained, the backstays and cap shrouds may have opened at the nips and splices or have actually given way. This, however, may be due, in great measure, to the fact that the backstays are connected to the mast at a higher point; the deflection of a mast (with the same bending force) increases as the square of the height, and as the stretch and stress in the rigging varies with the deflection of the mast, the higher its

[1] If the length of a shroud, measured on a suitable scale, represented its tension, then its transverse pull would be represented by its spread, and its compressive force on the mast by the height of the mast from deck to hounds. The actual staying or supporting effect on the mast is measured by the moment of the transverse pull, about the deck or mast wedging; *i.e.* the transverse pull of the shroud multiplied by the height of the mast from deck wedging to hounds.

point of attachment, the more severely is it tried. This is discounted to some extent by the greater length of the rigging, which enables it to stretch further to the same stress, and by the smaller angle which it makes with the mast; but, compared with the greater deflection of the mast, these matters have but a small influence. In view of this it is evident that the upper rigging should, if anything, be less tightly set up than the lower, for then all parts are more likely to be strained alike and to contribute fairly to the general strength.

Art. 376. Formerly it was the universal practice to **wedge the masts** at the second deck; later, they were as often wedged at the upper; now, they are practically always so wedged. Formerly, when extensible hemp lanyards were employed, it was distinctly advantageous to wedge at the second deck, for owing to the greater height of the mast from this to the hounds, it had so much greater natural flexibility that the shrouds were better stretched and able to exert a greater proportion of their full strength before it (the mast) gave way or was unduly strained. It has been computed that in such cases the combined strength of the masts and rigging might be increased by as much as 30 per cent. by wedging at the lower in place of the upper deck. With modern rigging, however, there is no such benefit; here an increase in the flexibility of the mast is of little or no value, for the rigging is so inextensible that even with the smaller deflection due to wedging at the upper deck, it reaches its proof stress and exerts its utmost strength before the mast bends so far as to injure itself; greater flexibility in the mast would not, therefore, increase the combined strength of it and the rigging.

In large wood ships the masts are always wedged at the lower deck, for the strength and rigidity of a wood hull is so inferior that, if wedged at the upper, the local side pressure of the mast would cause straining and leakiness of the deck and upper part of the hull. In steel and iron vessels, the hull may, of course, be built with ample strength to resist the straining tendencies of the masts (Art. 153). Upper-deck wedging has an advantage of a potential character, in that should the mast be carried away it would break above the deck, for, of course, it is just at its point of fixture—the wedging—that it is most severely strained; if, on the other hand, it were wedged at the second deck, it might break between decks, and, in falling, tear up the upper deck, to the danger of the ship; in some cases of dismasting this has actually happened. To strengthen the mast against the severe local pressure and nip-like effect prevailing at the wedging, its plating is locally doubled (Fig. 10, Plate 64); and when the wedging is at the second deck, Lloyd's rules require the doubling to extend above the upper deck, so that should the mast be carried away, it may not break between decks (Fig. 11).

Art. 377. When subjected to a deflecting force, a mast may be regarded as a beam; by the action of bending, the plating on the lee side is subjected to compression and that on the other to tension. If, as in a beam, the external force affecting it were only a deflecting one, the tensional stress would equal the compressive; actually, however, the latter is much in excess, due to the compressive or crushing effect of the weight of the mast and attached spars, and the downward pull of the rigging. Consequently, when a **mast fails**, it does so **from excess of compression**, the material on the lee side buckling and collapsing, somewhat in the manner shown in Fig. 9, Plate 64: if failure occurred from excess of tension, the riveted joints would pull asunder. The downward thrust to which the mast of a 1600 ton ship is liable, has been computed:[1] the total weight of

[1] "*Report on Masting.*"

the masts, yards, etc., was found to be 40 tons, and the downward pull of the rigging on the windward side—assumed to be strained to half its breaking strength—156 tons; these two combined give a total of 196 tons, which, when divided by the sectional area of the mast, was found to give a stress on the material of about 3 tons per square inch. This compressive stress of 3 tons must, therefore, be added to the compressive stress brought about by the transverse bending of the mast; and, consequently, if the material were capable of bearing, without injury, a maximum stress of 10 tons per square inch, then the mast could only withstand a bending force that would impose a compressive stress (and, of course, a corresponding tensile one) of 7, for the 3 tons, being added, would make it 10. In designing a mast, therefore, it is very necessary to consider not only its strength as a beam subject to bending stresses, but also those characteristics which affect its power of resisting excessive compression.

With the same additional weight of material the **strength of a mast** may be increased in two distinct ways: by making it of thicker plating, or of larger diameter. If the plating be thickened the strength will be increased in exactly the same proportion; the flexibility, however, will be unchanged, *i.e.* the mast will be capable of deflecting as far before breaking, although to so deflect it will require a greater force. The compressive strength will also be increased in the same proportion, for it varies as the sectional area; but a further increase will accrue from the circumstance that mere thickness increases the lateral stiffness of a plate against the buckling tendency of excessive endwise compressive stress. If now the diameter be increased and the thickness maintained, a much greater increase in strength will occur, for it varies with the square of the diameter; the flexibility, however, as measured by the proof deflection or the actual distance the mast can bend without injury will be reduced proportionately to the increase in diameter. As the sectional area varies as the diameter, the compressive strength of the mast will, of course, be increased in the same ratio.

It follows from the above, that if great strength were essential and flexibility unimportant, the better method of securing strength in a mast (with a given weight of material) would be to make it of large diameter and of comparatively thin plating; but a sufficient degree of flexibility is usually more important than strength, for it ensures that the mast will not suffer a severe stress in advance of the rigging: and, moreover, a special degree of strength in the mast itself is comparatively unimportant, for, as already seen, its resistance to side bending is, in any case, small compared with that of the rigging. If greater strength is desired, therefore, it would usually be better to secure it by the former method, *i.e.* by increasing the thickness of the plating; for although the gain in strength would be less marked, the flexibility would be maintained. A precisely similar strengthening effect to that obtained by increasing the thickness of the plating may be secured by fitting internal, longitudinal angle bars; and this arrangement is advantageous in that, while the bars do not reduce the flexibility of the mast, they greatly augment the lateral stiffness of its plating against buckling or collapsing tendencies. For this reason, therefore, large masts are always constructed with **internal stiffening bars**, usually three (see Fig. 3, Plate 64). With three bars, it is well to place one at the after side of the mast, and the other two symmetrically at the two forward quarters; for, as already noticed, a mast is least supported against a wind which tends to bend it forward and towards the side; and as, when so bent, the material at one of its forward quarters is in compression, it is that which would receive the most benefit from the stiffening effect of an angle bar.

Topmasts are also often provided with stiffening bars, usually two, which should be placed, one forward, and one aft. Masts are sometimes constructed with tee bar stiffeners (Fig. 4); these are made to serve as connecting strips for the longitudinal seams of the plating, so that when the butt straps of the end joints are placed within, the outer surface of the mast is perfectly flush.

Art. 378. The **mast-holes** in the decks are formed as shown in Plate 64. When a beam is severed, its ends are supported by fore-and-aft carlings, termed "*mast partners*" (Fig. 6); in many cases, however, where a beam would foul the mast, it may be curved, locally, so as to pass before or abaft it (Fig. 5). At the deck on which the mast is wedged the mast-hole must be strongly constructed, so that it may take the lateral pressure of the mast and distribute it to the deck beams. Formerly it was usual to provide fore-and-aft partners between the beams, one on either side of the mast-hole, and fit, between them and around the mast, thick chocks of wood (Fig. 12). Now, however, except in the case of very large masts, partners are dispensed with, the lateral pressure of the mast being well provided against by a stout deck plate, having around the mast-hole, pierced in it, a substantial coaming of bulb angle, which stiffens it and gives a bearing for the wedges (Fig. 10). Lloyd's rules require the breadth of the mast deck plate, if the deck is not plated, to be at least three times the diameter of the mast, and to be not less thick than the deck stringer plate; and, in the case of sailing-ships, that the hoop around the hole shall be of bulb angle, 1 inch deeper than that suitable for the frames; in steamers it may be of ordinary frame-angle size. As noticed in Art. 153, if the deck of a sailing-ship is not plated, diagonal tie plates are required in way of the mast-holes, to distribute the straining effect of the mast over a number of beams (see Plate 86). At those decks where the mast is not wedged the mast-hole requires no special strength; a plate is fitted to support the ends of the deck planks, and an angle-bar coaming is fitted around the hole, 2 or 3 inches clear of the mast (Fig. 10, Plate 64). At the mast-hole in the weather deck watertightness is secured by fitting a canvas *coat* around the mast, over the wedging. Where a mast passes through the deck of a light superstructure, only a canvas coat is fitted, for wedges would convey stress and cause straining of the light deck (Fig. 11).

Art. 379. In sailing-ships the masts step upon the keelson, where special steps or foundations are provided (Fig. 19, Plate 64). As the downward thrust may be very great, the step should be substantial; and the heel of the mast should bear uniformly thereon, with a large surface of contact. Sometimes, when the mast plating has become thin by corrosion, it has buckled or curled up just over the step; to avoid this, therefore, it is now always doubled at this part. At one time **mast steps** were formed as shown in Fig. 18, but this plan is objectionable, for, owing to the smallness of the surface of contact, the downward thrust of the mast may exceed the crushing strength of the material. In one case in which failure occurred, the plating of the mast tore and the keelson angles gave way as shown at A, Fig. 18; and the matter did not end here, for, with the sinking and consequent shortening of the mast, the rigging became slack and the mast went overboard, and took with it the others. The bracket shown below the step in Fig. 19 is necessary in large masts, to support the keelson, and so that the overhanging side portion of the step may be as unyielding as the part over the keelson. As the pull of the yards and rigging is more or less one-sided, it tends to turn the mast upon its heel as a pivot; to prevent this, therefore, a locking piece, in the form of

a stout angle or tee bar, is fitted in the step, the heel of the mast being slotted to pass over it. Wooden wedges or Portland cement are inserted between the mast and the coaming of the step; Portland cement is the better, in that it does not harbour moisture and cause corrosion. In steamers the angle hoop forming the step is sometimes fitted close to the mast, the latter being secured thereto against turning by three or four tap bolts. Small holes should be provided in the bottom of the step (or in the mast), so that the mast may act as an up-take ventilator, drawing foul or heated air from the bottom of the hold (Art. 443).

Art. 380. The **masts of steamers** vary greatly in size and in the work required of them. As a rule, they are short and lightly rigged, and at sea, therefore, their downward thrust is comparatively small. In most cases, however, steamers' masts serve also as derrick posts; very commonly each one carries two derricks, and in some cases four, two forward and two aft; and as a derrick is usually capable of lifting 5 tons, and in some cases 10 or 12, the mast may at times be loaded with a dead weight of 10, or even 20 tons; and, moreover, when the weight is slewed over the side, the rigging on the opposite side, being put in tension, may greatly increase the downward thrust. In many cases excessive compressive stress due to the derricks is avoided by extending the pivot-bars supporting the heels of the latter down to the deck, and pivoting them there instead of on the mast (see Figs. 3 and 7, Plate 61). From the above, it is evident that the strength required in the masts and steps is dependent, in great measure, on the arrangement of derricks.

When a steamer's mast steps on the double bottom, the step is merely an angle hoop, riveted to the tank top, with a cross locking piece. To avoid unequal pressure on the tank-top plating, the end of the mast should be cut with precision to the proper bevel. When a mast steps on the shaft tunnel, the top and sides of the latter must be suitably strengthened to take its downward thrust (see Fig. 17, Plate 64). It is now a common plan to step the masts on the lower or second deck, thus reducing the structural work and avoiding obstruction in the hold (Fig. 13, and Plate 110). In such cases the deck must, of course, be suitably stiffened, and well pillared below the mast; very commonly the latter falls close to a transverse bulkhead, in which case its downward thrust may be conveyed thereto by fitting a large bracket plate below the step.

When stepped on the second deck, the short "**housing**," or distance between the heel of the mast and the wedging, may result in excessive side pressure at these two places. Thus, whatever the bending moment affecting the mast above the wedging (whether by the wind or by weights lifted by the derricks), it must be balanced by a reverse moment of equal magnitude acting below the wedging. If, for instance (Fig. 8, Plate 65), the deflecting pressure acting at the top of a mast, say 48 feet long above the deck, were 5 tons, then, with an 8-foot 'tween decks, the lateral force acting in the same direction at the heel would be 30 tons, and the side pressure on the mast at the deck wedging would be these two combined, or 35 tons. If, now, the same mast were stepped on the bottom of a hold (Fig. 9), say 20 feet deep, the figures 30 and 35 would become 12 and 17. It is evident, therefore, that when a mast has a specially short housing, its strength, and that of the step and mast-hole, should be suitably proportioned for the more intense side pressures. In special cases, where it would be very inconvenient to pass a mast through the 'tween decks (perhaps on account of passenger accommodation), it may be housed in a socket built on deck, termed a "*tabernacle*" (Fig. 14, Plate 64). And in small vessels which pass under low bridges, and where, therefore, provision must be made for

lowering the mast, the tabernacle is designed to permit of its being hinged down fore-and-aft (Fig. 15). In view of the shortness of the housing, a tabernacle should, of course, be a substantial structure, and the heel of the mast should be of increased strength.

Art. 381. A **topmast** may be of wood or steel; in large, modern, sailing-ships it is always of the latter material. It may be distinct from the the lower mast, in which case it is termed a "**fidded**" **topmast** (Fig. 5, Plate 65, and Plate 63); or, if of steel, it may be built in one piece with it, the whole forming one long "**pole mast**" (see the mainmast, Fig. 1, Plate 62). To support the heel of a fidded topmast, *cheek plates* are riveted on the lower mast, one on either side (Fig. 5, Plate 65); these project bracket-like in front of the mast, and the heel of the topmast, passing between them, is upborn by a *fid*, a massive iron bar of rectangular section, which passes through a hole cut in the heel of the topmast and rests with its ends on the top of either cheek plate. The downward thrust of the topmast, due to the weight it carries and the pull of the rigging, may be very considerable; in the case of a mast 19 inches in diameter, it has been computed that at times it may equal about 86 tons, and as the projecting cheek plates must take this thrust, they must evidently be substantial and strong. They are, therefore, of thick plating, about 50 per cent. heavier than the plating of the lower mast; the upper edge is stiffened by a large angle bar, and the forward free edge by a half round moulding or small angle. As the whole thrust of the topmast is taken by the comparatively small fid passing through it, the thin plating of the mast immediately above must endure a severe crushing stress; and, accordingly, local strength is provided by doubling the plating in way of the fid hole, or by fitting within the mast, just over the fid, small vertical lugs, whose ends bear on the fid, and sometimes a cross diaphragm plate is fitted between the lugs. In some cases the thrust of the topmast has been in excess of the strength provided, the mast plating tearing over the fid, or the cheek plates buckling and bending. The lower shrouds are looped round the mast, over the cheek plates, and, to avoid a sharp nip, *bolsters* of hard wood are fitted on the top of the latter (Fig. 5, Plate 65).

The above method of fixing the heel of the topmast has been in vogue from the earliest period; its suitability is due to the circumstance that it permits of the topmast being "struck" or lowered, by withdrawing the fid and letting it slide down in front of the lower mast. It is not often, however, that a topmast requires to be lowered, and of late years it has become common to build it in one with the lower. But although this arrangement simplifies the constructive work very considerably, it is not always adopted, for a separate topmast is advantageous in that, should it be carried away, it may be readily renewed, a spare wooden spar being carried on deck for the purpose. In a number of the earlier ships, having steel pole masts, the upper or topmast portion was carried away, breaking off just above the termination of the stiffening bars of the lower mast. This, no doubt, arose not only from relative weakness, due to the abrupt stoppage of the stiffening bars of the lower mast, but from the greater rigidity that naturally prevails in the absence of the usual fidded union with the lower mast. Since then, pole topmasts have been strengthened by extending upwards two of the stiffening bars of the lower mast; in an ordinary fidded topmast, stiffeners are not required by Lloyd's rules unless its length exceeds 38 feet. It should be observed that while the taper in the diameter of a lower mast (from wedging to hounds) is usually about 17 per cent., that of a topmast and topgallant mast does not exceed about 2 inches; for the reason that the upper and topgallant yards travel up and down the mast on

a hoop, termed a "*parrel*" (Fig. 5, Plate 65), and if the taper were considerable this would have too much play on the mast. In steamers which navigate canals and rivers, having bridges, the topmast, if long, is arranged to telescope into the lower one, by suitable sheaves and a wire line, as shown in Fig. 4. The rake of the masts is merely a matter of taste; in sailing-ships the mainmast has usually a rake of about 1 inch to the foot, the fore and main-masts having $\frac{1}{4}$ inch more and $\frac{1}{4}$ inch less respectively. In steamers the rake may be twice as great, or there may be none at all.

Art. 382. Masts and spars, like other parts of the hull, are rarely built of iron, **steel** only being employed. If iron is used, Lloyd's rules require it to be of good malleable quality, to have a tensile strength of 20 tons per square inch, and to be capable of withstanding certain bending tests. These tests vary with the thickness of the plate; a $\frac{9}{16}$-inch plate must bend cold through an angle of not less than 25 degrees with the grain, and 8 degrees across the grain; for thinner plates, the figures 25 and 8 gradually increase, becoming 70 and 25 in $\frac{3}{16}$-inch plates (see Figs. 20 to 24, Plate 99). Although the greater strength of steel, compared with iron, admits of a general reduction in the scantlings of the hull of some 20 per cent., so large a diminution is not admissible in the case of the masts and spars. For the most crucial stress suffered by a mast is a compressive one, and although steel is about 50 per cent. stronger than iron under tension, its superiority is much less marked under compression. And, further, the mere reducing of the thickness of a plate involves a serious loss of lateral stiffness, so that the plate is less well able to resist the side buckling tendencies induced by severe endwise compression. The reduction made in practice varies from nothing at all in plates so thin as $\frac{1}{4}$-inch, to about 10 per cent. in $\frac{9}{16}$-inch plates. In very thin plates it would evidently be unwise to make any reduction, for although the strength might, when the spar was new, be equal to that of an iron plate, the reducing and weakening effect of corrosion would be disproportionately large. In old vessels, for instance, the thin plates of the yards (and even of the masts) are often corroded through in holes, and evidently, therefore, some surplus thickness is desirable.

Lloyd's rules as to the **diameters and scantlings of steel masts**, yards, etc., are given in tabular form. A short lower mast, say 48 feet long from heel to heel, is 16 inches diameter by $\frac{6}{20}$ inch thick at the wedging; thence, towards the head and heel, it tapers both in diameter and thickness (in some vessels, however, the lower masts are built without any taper). In a large mast, 96 feet long, the figures 16 and $\frac{6}{20}$ become 32 and $\frac{10}{20}$. Lower masts, whose length exceeds 84 feet, must have three stiffening angles (Fig. 3, Plate 64), varying from $3\frac{1}{2}$ by 3 by $\frac{8}{20}$ inch to 5 by 3 by $\frac{9}{20}$ inch, according to the length of the mast. Lower masts up to 75 feet in length may be built with two plates "in the round," *i.e.* with two strakes of plating (Figs. 1 and 2); if longer, with three strakes (Fig. 3). The three-strake arrangement is the stronger, for the end joints only extend one-third round the mast in place of half-way, and, as the longitudinal seams, owing to their double thickness, are in themselves a source of strength, the greater their number the stronger the mast. The stiffening bars are placed midway between the seams, and, of course, their end-joints should be properly connected. The masts of steamers, being only used for auxiliary purposes, are of smaller diameter and thinner plating than those of sailing-ships. Lloyd's rules allow a reduction of one-eighth or one-fifth in the diameter, according as square sails are or are not carried. And, similarly, in the case of the mizzen mast of a sailing-barque, which carries only fore-and-aft sails, a reduction of one-fifth is allowed.

To strengthen the mast at the **deck wedging, doubling plates** are fitted on each strake (Figs. 10 and 11, Plate 64). They are usually about 6 feet long, and their ends should be shifted clear of one another, so as to avoid a cross line of pronounced relative weakness; and this may be still better accomplished by cutting the ends, not square across, but with a slope, so that they may lie spirally on the mast (Fig. 10). When the mast plates are jointed in way of the doubling, distinct buttstraps should be fitted; for when the doubling is made to serve as a strap—as it sometimes is—the mast, at the joint, is only of single thickness, and the joint becomes a point of marked local weakness. The double thickness at the wedging is also useful as a provision against the reducing effect of corrosion; for, as the wooden wedges are apt to harbour moisture, corrosion may go on unseen; in old vessels in which doublings were not fitted, the mast plates are sometimes found so corroded at the wedging as to require renewal. The heel of the mast is also doubled (Fig. 19). In the case of steel topmasts, doubling plates are required in way of the lower-mast cap, which, of course, corresponds with the deck wedging of a lower mast; and in way of the fid and sheave holes.

With regard to the **riveting of the masts**, Lloyd's rules require all end joints above the wedging to be treble riveted, below this, double riveting suffices. They are usually overlapped; if butted, the straps should be placed outside, for they are more effective here, and the closeness of the riveting work is better observed. In sailing-ships the longitudinal seams of the lower mast are double riveted, those of the topmast being single. In steamers all longitudinal seams are single riveted. The rules of the Bureau Veritas permit of single riveting in the longitudinal seams of all masts in which angle stiffeners are fitted; so also do the rules of the British Corporation, which, at the same time, permit of the angle stiffeners in large masts being dispensed with, if the plating is thickened.

Art. 383. Lloyd's rules specify the **number and size of the shrouds, stays, rigging screws**, etc., required in three-masted sailing-ships of various tonnages. The sizes of ropes are always stated in circumferences. The fore and main lower masts of a small ship (between 300 and 400 tons) require four $2\frac{1}{2}$-inch shrouds; those of a large one (of 3000 tons), six $5\frac{1}{2}$-inch shrouds. The mizzen mast, being smaller, may have smaller shrouds, and one fewer. In a four-masted ship each mast, having a smaller spread of sail, may have lighter rigging; for such vessels, therefore, the tonnage (by which the requirements are decided) is assumed as four-fifths of the actual tonnage; and, similarly, in a five-masted ship, as three-fourths. All the ropes of the standing rigging are of galvanized steel wire; and for each size a minimum breaking strength is specified, which may be approximated to, in tons, by squaring the circumference and multiplying it by 1·8. To ensure that the wires forming the rope are of good malleable steel, not susceptible of injury by sharp bends, each one must be capable of being twisted round upon itself as a core, corkscrew fashion, and of being untwisted and straightened again without breaking.

Steel-wire rigging began to supersede iron-wire shortly after 1876, and it is now, of course, exclusively used. When of the usual material, a steel rope is about 80 per cent. stronger than an iron one; and in view of this, its adoption permitted of a considerable reduction in the sizes current with iron ropes; thus in place of a 3, 4, or 5-inch iron-wire rope, Lloyd's rules specify steel ropes of $2\frac{1}{2}$, $3\frac{1}{2}$, and $4\frac{1}{4}$ inches, which still leaves a surplus strength of from 20 to 30 per cent. Ordinary wire ropes are made from *crucible steel*, having a tensile strength of about 50 tons per square inch. For the rigging of yachts, a superior steel, known as "*plough steel*," is

generally used; here the tensile strength of the wires is about 100 tons per square inch.

Art. 384. Formerly the **bowsprit** was always composed of two spars, the bowsprit proper and the **jib-boom**. The latter was of wood and was arranged to unship by drawing inwards through the bowsprit cap (Fig. 2, Plate 65). Now, it is usually constructed as one steel spar, termed a "**spike bowsprit,**" the omission of a detached jib-boom simplifying the construction and reducing the work required of the crew (Figs. 3 and 6). As it is then considerably shorter, it reduces somewhat the area of head sail, but, with the four masts now adopted in all large ships, this is unimportant, for the fore mast is stepped nearer the bow. The bowsprit may be shipped in much the same way as a mast (Figs. 1 and 6), by passing it through a hole in the knight-head frame, where it is wedged, and providing a special abutment or step for its heel, within the forecastle; and formerly it was further secured by a *gammon hoop* placed outside the wedging. Sometimes it is riveted to the forecastle deck, its end being cut at a suitable slant and an external angle bar fitted around its edge (Fig. 3). Owing to the shortness of the bed, a bowsprit so fixed has a powerful lever-like action, tending to strain the forecastle deck; this, therefore, must be locally strengthened by thickening the deck plating and by placing the beams on every frame and connecting them to the frames by large knee plates (Fig. 3). The most severe stress affecting the bowsprit is that due to the vertical pull of the mast stays, accentuated by upward blows from the sea as the vessel plunges bows under. Lloyd's rules specify diameters and scantlings suitable for bowsprits of different length. At least two angle stiffeners are required, and in bowsprits over 28 inches diameter, four; and when of this size a vertical diaphragm plate is required in way of the wedging or bed, to strengthen the bowsprit against the upward bending forces (Figs. 1 and 6). And, further, the plating must be doubled in way of the wedging; or if the bowsprit is riveted to the forecastle deck, it must be thickened at this part. Bowsprits may be built with two or three strakes; if three, one of them is discontinued in way of the small diameter, jib-boom portion. The end joints are treble riveted, but, in a wedged bowsprit, those within the wedging may be double. The seams are single riveted.

The bowsprit is stayed downwards by the **bobstays** (see Figs. 2, 3, and 6, Plate 65). In a spike bowsprit there is, of course, an **outer stay** for the jib-boom portion. In a long bowsprit the outer stay may make with it so small an angle as to have very little vertical staying effect; formerly this was corrected by fitting a *martingale* or *dolphin-striker*, projecting as a distance piece or strut from the end of the bowsprit proper (Fig. 2); but with short spike bowsprits this is either omitted or made very short (Figs. 5 and 6). Owing to its large diameter and comparative shortness, a bowsprit has little flexibility (especially when riveted to the forecastle deck), and, accordingly, in order that the bobstay may give prompt and useful support, it is evident that it must always be perfectly taut; with this object, therefore, the inner bobstay is practically always a solid bar of round iron, and very often the outer stay as well. Sometimes a chain is employed, but this is not so efficient, for it is extensible, and cannot be stretched perfectly straight and taut, *i.e.* it must always sag slightly; in practice, however, this defect is minimized by providing it with a rigging screw. Bar bobstays have the disadvantage that they may be bent and damaged by contact with barges, tow ropes, etc.; in the case of the inner bobstay, this is provided against by making it very stout; for instance, whereas the sizes of chain bobstays, specified in Lloyd's rules, vary from $1\frac{3}{16}$ to $2\frac{1}{16}$ inches,

the diameters of bar bobstays vary from 2 to 4 inches; the tensile strength of the latter is more than double that of the former, but it is not made stout for tensile strength, but for lateral stiffness.

Art. 385. Large **yards** are always of steel; the smaller upper topgallant and royal yards are generally of wood. Lloyd's rules specify diameters and thicknesses for steel yards of different lengths. The diameter at the centre is $\frac{1}{48}$th of the length of the yard, that at the ends being 50 per cent. smaller. The thickness of the plating varies from $\frac{3}{16}$ inch (throughout) in a yard 32 feet long, to $\frac{8}{20}$ inch in one 96 feet long, diminishing towards the ends by about 50 per cent. Yards are not provided with stiffening angles, for they are not, like a mast, subject to excessive compressive stress. They are built with two strakes of plating, the end joints being treble riveted and the seams single. Doubling plates are fitted at the centre, to strengthen them against the local stresses prevailing at the sling and truss hoops, by which they are suspended from the mast (Fig. 13, Plate 93). The procedure adopted in the actual building of the masts and yards is described in Art. 528.

Art. 386. An immense quantity of **smith-work** is required in connection with the masts and rigging of a sailing-ship; and, as regards material and workmanship, it should be of excellent character, for, as already noticed, the failure of even a small part may have disastrous consequences. Fig. 1, Plate 62, shows the general arrangement of the masts and rigging of a three-masted barque, and Plate 63 that of a four-masted one.[1] Some of the more important items of mast and rigging smith-work are shown on Plate 62. It should be observed that, in the matter of design, mast mountings vary greatly, the desired result being obtainable in various ways. The lower **mast cap** (Fig. 2, Plate 62, and Fig. 5, Plate 65) is a particularly massive forging. Like all other fixed hoops, it is shrunk tightly on to the mast, and, as a security against the chance of its becoming loose, a few rivets are introduced. The cap should be fashioned to the shape of the mast, for this may not be perfectly circular. Sometimes, owing to imperfection in the fit, the cap has loosened at sea—a serious matter for the security of the topmast and other spars. The topmast passes loosely through the cap, where it is wedged; and the head of the lower mast is covered with a sheet-iron hood, which should be so arranged that, while excluding water, it may act as a sort of mushroom ventilator, allowing air from the hold to pass up the mast (Fig. 17, Plate 75).

As the solidity and soundness of a weld is less assured than that of the solid forging, it is always desirable to avoid welding as far as practicable in important parts. The actual amount of **welding work** in any particular forging may vary very considerably; in high-class smith-work it is reduced to a minimum, even complicated parts being **forged** almost entirely **from the solid**, by moulding them under the steam hammer with tools specially prepared for the purpose—termed "stamps," "dies," or "cresses." Such work is slow and costly, but, as regards reliability, is greatly to be desired. In Government work welding is avoided wherever possible in all forgings. To avoid extensive smithing and welding work, **mast caps** have sometimes been made of **cast steel**, but this practice has met with little favour, if only from the circumstance that it involves the making of costly wooden patterns. When of cast steel, Lloyd's rules require stringent tests to be made, to ensure that the steel is of good ductile quality and that the completed casting is sound (Art. 570).

[1] The registered dimensions of the latter vessel are a length of 317·6 feet, breadth 44·2 feet, depth 24·6 feet; the gross tonnage being 2817.

A lower yard is fixed aloft in a sort of permanent fashion (Fig. 7, Plate 62, and Fig. 5, Plate 65); it is suspended by a short *sling chain*, one end of which is usually shackled to an eye-plate on the mast, and the other to an eye on the *sling hoop* of the yard; and it is held out from the mast (so that when braced round it may clear the rigging) by a *truss bow*, which is provided with joints or pivots to permit of the yard being braced round, or topped up. The topsail, and topgallant yard are suspended from a small *crane*, pivoted to the mast cap, a truss bow being fixed to the yard and pivoted to the crane (Fig. 2, Plate 62, and Fig. 5, Plate 65). Upper topsail and upper topgallant yards, which require to be raised or lowered, are connected by a pivot to a hoop termed a "*parrel*," which runs up and down on the mast (Fig. 4, Plate 62, and Fig. 5, Plate 65).

CHAPTER XXVII.

Art. 387. All vessels must, of course, carry anchors, **cables,** tow ropes, and warping and mooring lines. Lloyd's requirements in this respect are regulated by a numeral termed the "equipment number," which is practically the ordinary plating numeral, increased for all large erections above the upper deck. Sailing-ships require longer and stronger cables and heavier anchors than steamers, for, owing to their masts, spars, and rigging, their anchorage is less secure, and, having no power of self-propulsion, they are more dependent on their "ground tackle." The length of cable varies from 120 fathoms in a small vessel to 330 in the largest, the diameter of the material of the links varying from $\frac{11}{16}$ to $3\frac{1}{2}$ inches. Cables are made up of 15-fathom lengths, connected by joining shackles, the total length on board being divided into two equal portions, so that two anchors may be available simultaneously. Steel is not used for cables, for as each link must be welded, it is found better to use iron of good quality, having good welding properties. The usual form of link is shown in Fig. 4, Plate 66. It is known as the "Admiralty pattern," and is adhered to more or less closely by all cable manufacturers; if there were much variation, each windlass would have to be designed to suit the particular cable in use. The cross *studs* are of cast iron, merely jammed in place; they slightly increase the strength of the cable, and prevent the links from collapsing, jamming, and forming "*kinks;*" they sometimes fall out and require renewal. In small cables ("unstudded" or "close-link" chain) studs are sometimes dispensed with, but the links are then of reduced size. They are not so strong as stud-link cable, and under severe stress the links are apt to collapse and grip one another.

It is required by Act of Parliament [1] that all **cables** for British ships shall be **tested** by tensile stress. There are two tests—the *proof* and the *breaking;* the cable itself is only subjected (each 15 fathoms separately) to the proof test, which varies from 0·66 of the statutory breaking *test* in a small chain to 0·71 in large. The **breaking test** is only applied to a short experimental length of three links, cut from each 15 fathoms; and as the Act requires that these must not fail or even yield under the test, some 15 to 20 per cent. surplus strength is usually provided. When a cable is tested to destruction, fracture occurs at the side of a link, and as there are two sides it might be thought that the strength of the cable would be double that of the single bar from which the links are made, actually, however, it is only from 55 to 75 per cent. greater. The statutory breaking test varies from 27 tons for a 1-inch cable to 204·1 for a 3-inch, which gives respectively a stress of 17·2 and 14·4 tons per square inch of the combined sectional area of both sides of the links.

The statutory **proof stress** is supposed to be within the elastic limit of the cable, for if greater a permanent stretch would occur in the material of the links, and weak points might be seriously strained. It is a difficult

[1] *The Chain Cables and Anchors Act* of 1864 to 1874.

matter to decide what proportion of the ultimate strength of a cable is the elastic limit; if it were the same as that of an iron bar it would lie between 50 and 60 per cent. of the ultimate strength, consequently, as the proof stress is found by experiment to average about 60 per cent. of the actual breaking strength, it is probable that it is often in excess of the elastic limit. The Marine Department of the United States Government have thought it proper to adopt a smaller proof stress than that required by statute in this country; it is so chosen as not to exceed 50 per cent. of the minimum breaking strength of the cable. And the rules of the Bureau Veritas also specify a smaller proof stress.

At one time it was common, when launching a ship, to make use of her cables to bring her up when she left the ways. That this may be unfair treatment is evident from the fact that the severe jerk, which generally occurs, often breaks them. While employing the cables, however, evil results may be avoided by introducing a length of smaller chain, whose breaking strength is well below the proof strength of the ships cable, for then before the latter can feel any undue stress, the former will break. In cases where a vessel is pulled up by several cables, the last pair, which only comes into operation when the vessel's momentum has been largely reduced, is still very commonly the ship's own cables.

The statutory **tests for unstudded cable** are less severe than those for stud-link cable; the proof stress is one-third less, and the breaking stress is twice this reduced proof stress, which makes it rather less than that required for a stud-link cable. That the proof stress should be smaller is very necessary, on account of the tendency of the links, in the absence of studs, to collapse.

It is required by statute that the end and two intermediate links of each 15-fathom length of cable shall be stamped with the particulars of the test; and a certificate, having the same particulars, is issued with each cable. There are only seven cable and anchor testing establishments licensed by the Board of Trade for carrying out the act, all of which are controlled by Lloyd's Register.[1]

Art. 388. It is also required by statute that **anchors** for British ships, which exceed $1\frac{1}{2}$ cwt. in weight, shall be **tested.** The shank is pulled in one direction and the flukes in the other, with the object of testing the efficiency of the welds and of the material generally. The stress applied varies from about 6 tons in a small anchor, weighing without its stock $3\frac{1}{2}$ cwt., to 75 tons in one of 122 cwt. One of the many varieties of patent stockless anchors, now in common use, is shown in Fig. 9, Plate 66. The old-fashioned stock-anchor (known as the Admiralty pattern) is still often employed, it being thought by some to be more reliable in embedding itself and holding in the ground (Fig. 2). The stockless and other patented varieties, however, may hold equally well, and as, owing to their compactness, they are more easily stowed and manipulated, they are now generally preferred. Formerly, anchor stocks were of wood, their purpose being merely to keep one of the flukes downwards on the ground; but now, of course, they are always of iron, and Lloyd's rules require their weight to be not less than one-fifth that of the whole anchor. In the case of stockless anchors, Lloyd's rules require the weight of the head portion to be not less than three-fifths of the whole weight (which need be no greater than that of a complete ordinary stock-anchor), for in these anchors the burying and holding power might be seriously reduced if the head were light and the less useful shank heavy.

[1] An interesting account of chain cables, their early history and the various legal enactments concerning them, will be found in Mr. Thomas W. Traill's book, "*Chain Cables and Chains.*"

Stockless anchors are usually of cast steel. They are subject to the same statutory tests as ordinary iron anchors, also, if of cast steel, to certain **preliminary tests** to ascertain if the casting is sound and of good, ductile steel.[1] The head and shank of a stockless anchor are separate parts, pivoted together, and if both are of cast steel, both, of course, are tested; as a rule, however, the stock, being of simple form, is a forging. The tests are of three kinds, known as (1) the "percussive" or "drop test," (2) the "hammering," and (3) the "bending test."

The **percussive test** consists in lifting the anchor, or each of its parts, to a certain height (15 or 12 feet, according as its weight is below or above 15 cwt.) and letting it drop on an iron slab.

The **hammering test** is made after the drop test, and consists in suspending the casting, and striking it all over with a hammer weighing not less than 7 lbs., so that by the clearness of the ring it may be judged whether or not it is free from flaws such as may have existed from the first or have developed as a result of the drop test.

The **bending test** is made with a piece cut from the casting, a tongue of metal being sometimes cast on it for the purpose. When turned down to a diameter of 1 inch this must withstand, without sign of fracture, being bent cold by hammer blows through an angle of 90 degrees (*i.e.* at right angles with itself), the internal radius at the knuckle being not less than $1\frac{1}{2}$ inches. Four, but not more than four, test pieces may be tried, and the casting is deemed satisfactory, as regards ductility, so long as any one of them passes the test.

Further, it is required that all cast-steel anchors shall be **annealed**; the process to occupy at least three days for small anchors and six for large (Art. 564).

Anchors are classified as, "**bower**," "**stream**," and "**kedge**" **anchors**, according to their relative size and particular purpose. Lloyd's rules require all vessels to carry a kedge, a stream, and (excepting vessels under 300 tons) three bower anchors. The kedge is the smallest anchor, it is used for "kedging," *i.e.* warping or hauling the ship along in a channel; the stream is about twice the weight of the kedge, and it is used for a similar purpose. The bower anchors are, roughly, three times the weight of the stream; they are the main anchors by which the ship rides; two of them are always in readiness for immediate use, one being shackled to the port and the other to the starboard cable. The third is a spare anchor; it is usually heavier than the others by about 15 per cent., and is sometimes termed the "best bower." Very large vessels usually carry two spare bowers, or four in all.

Art. 389. The locker for the cable is built in the hold or peak, by fitting a light transverse bulkhead, of iron or wood, about 4 feet from the collision bulkhead, the locker space between these being divided for the two cables by a fore-and-aft division (Plates 10, 109, and 110). In most cases, independent side walls are provided, for if the locker extended from side to side of the ship it would be unnecessarily large. When it does extend to the vessel's sides, the latter are covered with ceiling planking. As usually constructed, the **chain locker** forms a deep shaft, into which the cables, passing down the deck pipes, may stow themselves automatically, with little need for hand trimming. In some cases the locker is placed between two lower decks, but this is a less suitable arrangement, because, to secure the necessary

[1] These special tests were recommended in the report of the Committee appointed by the *Board of Trade* in 1886, to consider the question of tests for cast-steel anchors, the manufacture of which had not been contemplated in the *Chain Cables and Anchors Acts of* 1864 *to* 1874.

internal capacity, a large floor area is required, and, consequently, the cables cannot coil themselves away, but must be spread out by manual labour; and, to provide room for the men, there must be about 3 feet of head room between the cable (when all is stowed) and the deck overhead. In any case, when the cable is being hove in, men are usually employed in the chain locker to prevent it from twisting and forming kinks, for, of course, if it did, it might jam in the deck pipe the next time it was run out. The inner end of each cable is fixed in the chain locker, sometimes by merely uniting the two ends, under the keelson or fore-and-aft iron division, otherwise by shackling each one to a large eye-plate riveted to one of the vessel's floors, or to the lower part of the collision bulkhead. In some cases, where the cable has not been secured in this way, it has all run out and been lost; and when ranged for inspection on the bottom of a dry dock, the inner end, not known to be free, has sometimes lashed out to the jeopardy of the men engaged in ranging it below.

Art. 390. The cables pass from the locker, up through the decks, by **chain or deck pipes**; the windlass is usually placed directly over the pipes, and the cables, each one passing over its "cable-wheel," are led overboard through the **hawse pipes**, or **hawse holes** (Fig. 9, Plate 66). The hawse pipes should be so placed as to give a straight lead for the cables, *i.e.* they should be the same distance apart as the cable-wheels of the windlass. According as the cables pass directly through the vessel's bow plating, or, firstly, down through the upper or forecastle deck, so the hawse hole is merely a cast-iron rim (Fig. 12), or a pipe (Fig. 9). They must be massive and strong, for when the vessel is at anchor with the cable leading astern, they may be subjected to severe stress; and they may suffer intense shocks and vibratory effects when the anchor, on being dropped from the forecastle deck, suddenly jerks the cable out of the locker. They are usually of cast iron, but when large they are sometimes of cast steel. They should have a massive, easily curved lower lip, for it is this part that suffers most pressure from the cable, and if the vessel is often at anchor, it may become worn or deeply scored—the hawse pipes of old vessels have sometimes to be renewed from this cause. The thickness of the hawse pipes varies from 1 to $2\frac{1}{2}$ inches, and the internal diameter should be ample to pass the largest joining shackle of the cable.

Formerly, the anchors were always stowed on the forecastle deck; but in order to save the time and trouble of getting them on deck, and to permit of their being readily dropped overboard, **self-stowing anchors** are now nearly always adopted. These have no stock, so that the shank may be pulled right into the hawse pipe, leaving only the flukes outside (Fig. 9, Plate 66). In considering the movement of the anchor as it is pulled into the hawse pipe, it is evident that the lower part of the latter must receive a severe nip; for when the anchor—hanging vertically—reaches the pipe, it cannot enter until it is forced up into line, by the pressure of its contact with the lower lip of the pipe and by the pull of the cable; these two forces may be very intense, for they act with small leverage, and, to minimize them, the pipe should, evidently, be disposed, as far as possible, vertically; or its mouth should be large and trumpet-like. Care should also be taken that, when the anchor is pulled up tight in the pipe (it is usually kept home by attaching a rigging screw to its upper end) its projecting flukes cannot move and chatter when struck by the waves; to secure this condition external chocks or angle lugs are sometimes fitted on the shell, to take contact with the flukes.

The **hawse pipes** are cast from wooden patterns, fitted in place in the ship. The outer end is connected to the shell by rivets passing through

its lip, or through a flange cast on it for the purpose; and, to give a rigid foundation and attachment, the shell plating is locally thickened or doubled (Figs. 9 and 12, Plate 66). One at least of the vessel's frames requires to be severed, in way of the hawse pipe, and to maintain the rigidity of the side against the straining effects of the pipe, the severed ends of the port and starboard frames may require to be connected by a cross beam or stiffened plate. When the hawse pipe is a mere rim, thick chocks of teak wood are sometimes fitted within the vessel's shell plating (Fig. 13), so as to give a solid foundation, and the better to support the inner lip of the pipe. The top end of a pipe which passes through the upper or forecastle deck is not usually secured to the deck, it merely pierces it, and a cast iron, slab-like frame is fitted over it, provided usually with grooved ledges or lugs to take a plate cover (Fig. 9). Care should be observed to secure watertightness in the forecastle deck where pierced by the pipe, for leakiness is not unusual at this part, and is difficult to correct. Very long hawse pipes are sometimes supported at mid-length by a cross plate or beam, but this is of questionable utility. Plugs or plate covers are provided for those hawse pipes which enter the forecastle, so that when the vessel plunges bow-under, the water may not rush up the pipes and flood the forecastle; they are usually fitted from within, but sometimes hinged plate covers are fitted on the outside.

Sometimes, especially in sailing-ships, **double hawse holes** are provided, one on either side (see Fig. 6, Plate 65). The additional pair is useful if at any time a third anchor should be required, as when lying at anchor in an exposed roadstead. Sometimes it is provided merely for towing purposes, in which case it is formed like a mooring pipe, so as to offer a straight fore-and-aft lead for the tow-rope; the ordinary hawse pipes cannot be used for this purpose, owing to the presence of the cable. In ordinary cases the tow-rope is passed over a fair-lead on the forecastle deck (Fig. 9, Plate 66), but if it should be required to tow in heavy weather at sea, the tow-rope may be more safely and easily manipulated when passed through a hawse hole, from within the shelter of the forecastle. Sometimes mooring pipes are provided on the forecastle deck, in the rising-chocks, close to the stem (Fig. 9, Plate 66, and Plate 109), they are more efficient for towing purpose than fair-leads, for the tow-rope cannot be jerked out of place.

Art. 391. The anchors are such heavy masses that special means must be provided for dropping them overboard and lifting them on deck with expedition and safety. Even when self-stowing hawse-pipe anchors are adopted, means are still often provided for working the spare-bower or stream anchor. To get an ordinary anchor on deck after it has been hove above the water by the cable and windlass, a tackle (termed the "fish tackle"), suspended from a **davit** or **crane**, is hooked into an eye fixed on its shank (at the centre of gravity of the anchor), and it is then run up and deposited on deck, where it is lashed down to ring-bolts. Formerly, davits were always provided for this purpose, usually two on each side, one, the *cat davit*, for lifting the stock end of the anchor, and the other the *fish davit*, for lifting the fluke end. Now it is usual to substitute a single centre-line crane (see Plate 63, Fig. 10, Plate 66, and Plate 108). Anchor davits and cranes must be strong, the latter more particularly, on account of its long outreach; because the load lifted may exceed the weight of the anchor, for there is the attached cable, and sometimes a large mass of clay may come up with the anchor, or both anchors may come up together, and, further, the load actually lifted may be virtually increased by pitching movement of the vessel. Lloyd's rules provide a table giving the

dimensions of cranes for anchors of different weight and cranes of varying outreach.

The usual method of **dropping an anchor** (when stowed on deck) is, first to place it, by means of the davit or crane, in a position overhanging the gunwale (Fig. 2, Plate 66), holding it back temporarily by looping around it two small chains (the *shank-painter* and *cat-stopper*), one towards either end of the shank; one end of each chain is fixed on deck and the end link of the other passed over a sort of *toggle* or *trigger*, which, when released by a simple mechanism (Fig. 1), at once frees the anchor. In warships and some merchant vessels, the anchors are stowed on specially constructed, inclined beds, so that when released they may at once slide overboard, thus avoiding the preparatory work of hanging them over the gunwale (Fig. 11).

Sailing-ships are usually provided with **catheads** (Fig. 3, Plate 66). These serve the purpose of anchor davits or cranes, but they cannot deposit the anchor on deck. To do this a second tackle, the fish-tackle, is required, which may be suspended from a davit, or, in the absence of a davit, from the fore topmast. A cathead is advantageous in that it possesses great strength and forms a convenient means of dropping the anchor, for when this is about to be used, it may be suspended from it, in the loop, or bight, of a small chain, one end of which, when let go by a suitable toggle arrangement, at once releases the anchor (see Fig. 3). Catheads also form convenient points of attachment for the fore sheets. Formerly, they were always of oak or greenheart, but now they are made of plates and bars.

Art. 392. The **windlass** is a mechanism requiring enormous strength, both in itself and in its attachment to the deck; because, when the vessel is riding at anchor, it takes the whole pull of the cables. In extreme cases the latter may be pulled asunder, and, of course, even then, the windlass should not suffer, for if rendered inoperative it would not be possible to work the remaining cable. Although windlasses vary greatly in design, their mode of working is much the same. One of ordinary type is shown in Figs. 5 and 6, Plate 66, and it may be described generally as follows. Towards either end of the main horizontal spindle A B, (which is suitably geared to the driving engine), there is a large **cable-wheel** ("*cable-lifter*," "*cable-holder*," or "*wild cat*"), this is a kind of drum, having a deep groove in which projecting whelps engage with the links of the cable. Each cable, on its way from the locker to the hawse pipe, passes over its particular cable-wheel, the movement of which regulates that of the cable, paying it out, heaving it in, or holding it fast. In order that the one cable may be worked independently of the other, the cable-wheels are not fixed permanently to the driving spindle, but are connected therewith by a frictional coupling F; and in order that, when uncoupled, the cable may be held fast, or payed out slowly or quickly, each cable-wheel is provided with a frictional band brake E. The coupling is also usually a frictional one, in the form of a slightly tapered, or conical hub F, projecting from the cable-wheel, which fits into a similarly tapered recess in a contiguous wheel keyed permanently to the spindle. The engagement or release of the coupling is effected by sliding the cable-wheel along the spindle, so that its tapered hub may enter or leave the recess; this movement being effected by means of a disc-like nut H, working on a threaded part of the spindle just outside of the cable-wheel, which, when turned by hand, pushes the cable-wheel forward by mere contact, and pulls it back by means of projecting catches which hook over a projecting rim on the outer hub of the cable-wheel.

A coupling on the **frictional principle** is advantageous in that should the cable, when in process of heaving up, give a sudden or abnormal pull, it may overcome the friction of the coupling, run out momentarily, and thus avoid straining itself, the spindle, and the wheel and worm gearing of the steam engine; and further, though the engine may be in rapid motion, a frictional coupling may be engaged or disengaged without shock. To let the cable run out, its cable-wheel must first be uncoupled, its movement being then regulated by the band brake E (Fig. 6, Plate 66), which is operated by means of a hand wheel or screw K. It is this band brake that takes the pull of the cable when the vessel is at anchor, its power being practically unlimited.

A **band brake** (see Fig. 6, Plate 66) is, fundamentally, an incomplete flexible hoop (of iron, usually lined with elm wood), whose two ends, when drawn together, so tighten it upon its wheel, that it and the wheel practically become one; little force is necessary to tighten the band, for the friction between it and the revolving wheel is alone capable of producing the required effect. To prevent the band from turning with the wheel, it is "anchored" to a fixed point, by a link L, attached to one of its ends, or by the end itself. The action of the brake depends on which end is connected, for a band brake can only be put in operation when the wheel revolves in such a direction as will carry the free end towards the fixed; for then, by mere frictional contact with the wheel, the band is tightened around it, any further tendency of the wheel to move resulting in an instantaneous and enormous increase in the tightness or grip of the band. However tight the band, it may at once be released by merely opening the gap between its ends, for, of course, this at once slackens it and destroys the friction.

It will be observed from Fig. 6, Plate 66, that the **pull of the cable** on the upper part of the cable-wheel tends to pull the windlass forward, and at the same time to tilt it over; but as the pull of the cable is exactly balanced by the pull of the connecting link L, of the band brake (which, therefore, may be regarded as a continuation of the cable), and as this passes downwards through the deck, it follows that the windlass, by the mere pull of the cable, is forced downwards on its bed, thus increasing its resistance to displacement. The single force that is equivalent to the pull of the cable and of the brake is shown in Fig. 6 by the diagonal arrow. When the cable leads forward from the under side of the windlass, and the band brake is "anchored" as shown in Fig. 7, the pull of the cable only tends to haul the windlass forward, there is little or no toppling tendency, and no stress on the spindle. In some windlasses the fixed end of the band brake acts through a spring or buffer, placed below the deck; this provides a certain cushioning effect, allowing the brake and cable-wheel to revolve together through a small arc, and thus mitigates the concussive effects that may be brought about by any sudden jerking or surging of the cable.[1]

A band brake of ordinary type must be slacked off when it is required to haul in the cable, for when once firmly locked it prevents both forward and backward movement of the cable-wheel. In some windlasses,[2] however, the brake is so designed that although hard-on as regards paying-out movement of the cable-wheel, it does not prevent hauling-in movement, that is to say, while it prevents the cable from running out, it does not prevent the engine from hauling it in. There is an advantage in thus not having to slack off the brake before starting the engine, for the brake in its normal condition is hard-on, and need only be slackened when it is required to pay out cable.

In steamers the **windlass** is always worked by steam. Its **driving engine** is usually incorporated with it, otherwise it may be placed

[1] *Clarke, Chapman's Patent Windlass.* [2] *Napier's Patent Windlass.*

somewhere near; in very large vessels it is sometimes placed on a lower deck, and drives the windlass above by means of a vertical shaft; this is the plan adopted in warships, the engine being placed below the protective deck. In **sailing-ships** the windlass is usually worked by hand, but most large ships have a steam winch amidship which is arranged to drive the windlass by a **messenger chain**, engaging with sprocket wheels on either mechanism. In all windlasses, provision is made for driving by hand, usually by means of a long rocking beam or lever and pawls. If the windlass is placed in the forecastle, it is very commonly arranged to drive a **capstan** on the forecastle deck above (Fig. 6, Plate 66), in which case the necessary hand power may be applied through the capstan bars. A capstan on the forecastle deck is useful for hauling in warping or mooring lines and tow-ropes, and for the cat-fall when working the anchors. They are sometimes arranged with a two-speed gear, so that they may quickly overhaul the slack of a line. In the absence of a capstan, warping ends are usually provided on an extension of the windlass spindle. The windlass must be securely fixed to the deck. The deck itself is strengthened; if not plated, local plating is fitted, special pillars are introduced, and sometimes the beams are of increased strength. If there is a wood deck, thick planks are fitted at this part, and wood chocks should be fitted between the beams, to take the holding-down bolts.

Art. 393. Most vessels are provided with "**cable**" or "**bow-stoppers,**" placed between the windlass and the hawse pipes (Figs. 8 and 9, Plate 66). They form an auxiliary means of holding the cable, but for this purpose they are much less efficient than the cable-wheels of the windlass; they may be useful, however, in an emergency, if, for instance, when at anchor, it should be required to take the cable—or its pull—off the windlass. Formerly, when vessels had old-fashioned windlasses, bow-stoppers of some sort were essential, for when working the cable it was necessary to adjust the position of its coils on the windlass barrel, and this could not be done while there was a strain upon it. The mode of action of the stoppers is indicated in Fig. 8. The shaded block when elevated permits the cable to run freely over the top of the stopper, but when lowered, as in Fig. 8, the shoulders S present themselves, catch the end of one of the links, and stop the cable. The movement of the block is effected by an external lever, which works an eccentric pivot or crank within the block. The stopping effect is, of course, very sudden (it is referred to as a "*dead-nip*"), so that it would be dangerous to attempt to arrest the cable when running out. It is evident that, owing to the comparatively small base of attachment of the stopper, it is inferior to the windlass in resisting a heavy pull of the cable.

Art. 394. The requirements of the Board of Trade, as regards **boats and life-saving appliances,** are such that practically all sea-going vessels must carry sufficient boats for all the people on board.[1] They must be placed under davits, ready for lowering; but where, through limited space, this may be impracticable, some may be stowed elsewhere, or collapsible boats or life-rafts may be substituted for ordinary boats. At least one half of the boats must be first-class lifeboats, of wood or steel; they must have watertight air cases (of copper or other suitable material) secured inside, having a volume equal to one-tenth the internal volume of the boat, or one half of this may suffice if the other half is represented by external cork fenders.[2] The remaining boats need only have half as much buoyancy

[1] Full information on this subject will be found in the official publication "*Regulations and suggestions as to the survey of the hull, equipments, and machinery of steam ships carrying passengers.*"

[2] One and a quarter cubic feet of cork is taken as equivalent to one cubic foot of copper air casing.

apparatus—except two, which need have none. Steel boats are required to have such additional buoyancy apparatus that, when waterlogged, they may be no less buoyant than those of wood. The number of people a boat is reckoned as fit to carry depends on the sitting room and on the internal volume or buoyant power. Ten cubic feet is the minimum space required for each passenger, so that, as regards buoyant power, the boat's cubic capacity divided by ten gives the limiting number; in many boats, however, there would not be sitting room for so many people, in which case it is this which decides the carrying power. To avoid the tedious work of accurately calculating the internal volume of each boat, the simple, approximate rule is adopted of multiplying together the extreme length and breadth and the internal depth, and this again by the coefficient of fineness 0·6.

Small boats are usually built of **yellow pine**, clinker fashion; they become leaky by exposure to the sun and wind (due to warping and shrinking of the planks), and as they are neither very strong nor rigid, they alter shape unless well supported. In high-class vessels the larger boats are often of **teak wood**, in two thicknesses of half-inch planks, crossing one another diagonally. Teak wood is strong and durable, and as the grain of the one thickness crosses that of the other at right angles, a boat so constructed is little affected by exposure to the weather and is immensely strong and rigid. They have the disadvantage, however, of being more than twice as heavy as ordinary pine boats. **Steel lifeboats** are now largely employed. They are built of two sheets of metal, pressed to shape, one for the port and one for the starboard side, riveted to a continuous bulb bar forming the keel, stem, and sternpost, and reinforced with stout wooden gunwales and thwarts. They are of the double-bowed or whale-boat type, a form specified by the Board of Trade for all lifeboats. Their weight is much the same as that of diagonal, teak-wood boats, but they have the great advantage of durability; when subjected to blows which would destroy a wood boat they may, though battered and misshapen, remain perfectly watertight.

Although there may be sufficient boats for all on board, the provision does not, of course, always ensure the saving of life, for not only may the weather be too boisterous for the navigation of crowded small boats, but it may be found impossible to make the embarkation. If the disaster to the ship is sudden, there may be insufficient time to lower all the boats, or if the vessel should take a heavy list, the boats on the high side might not overhang the water. Further, except the sea be calm, the lowering of a heavy boat, crowded with passengers, is a terribly risky operation, for when suspended from the davits by long tackles, any rolling movement of the ship may cause her to swing with such violence, away from, and then against the ship's side, as to smash her to pieces; or, if a passing wave should lift her for an instant, and she be not at once released simultaneously from both tackles, she may be capsized or up-ended. The expeditious and safe lowering of the boats depends, of course, not only on the efficiency of the launching and lowering arrangements, but on the discipline and training of the crew; in high-class passenger vessels both of these matters receive careful attention.

Art. 395. In large, modern, passenger vessels, the numerous boats are usually stowed out of the way on a light boat, or shade deck, not used by the passengers (Plate 108). In others, they may be stowed on the bridge or upper deck, or above this, out of the way, on **boat or skid beams** (see Fig. 5, Plate 67). When stowed on a deck used by passengers, they obstruct and occupy valuable space; in fine weather, however, they may be swung outboard from the davits. They sit in **chocks or cradles**;

one pair near each end is usually sufficient, but with long boats there should be three pairs, for boats of the usual slender construction, if not well supported, gradually sink downwards between the chocks and become permanently misshapen. Sometimes the keel is supported all fore-and-aft, in which case, one pair of 'midship chocks may suffice to hold the boat erect—an arrangement which tends to expedition in launching. They are held down in the chocks by chains termed "gripes" (Figs. 4 and 8), which hook over the gunwale and are provided, each one, with a sliphook to permit of instantaneous disconnection (see A, Fig. 4). If the vessel's rail is outside of the boat, the chocks are elevated to its level, so as to avoid the necessity of lifting the boat over it when launching (Fig. 4). The chocks are then usually supported on cast-iron pedestals, bolted to the deck (see Figs. 2 and 4). Sometimes, however, portable pedestals are provided (Fig. 3), so that when the boats are swung outboard by the davits they may be removed, and thus leave a clear deck for passengers. In many passenger vessels the boats are stowed on the rail, with only inside chocks, as shown in Fig. 8. This is an excellent arrangement[1] as regards speedy launching, and as only one-half of the boat overhangs the deck, there is comparatively little obstruction. It will be observed that the keel is held in place by a fore-and-aft angle-bar bolted to the rail, and by catches, B, which, when it is required to launch the boat, may be lowered by moving the rod C. This arrangement, it will be noticed, requires the davits to be further apart than the length of the boat.

Boats' chocks must be so arranged that the boats may be launched outwards without any preliminary lifting, for to do this would involve delay, and with only a few men at the tackles it might be impracticable, especially if, as is common, the tackles have become stiff through disuse. The chocks shown in Figs. 1 and 4, Plate 67, are the kind generally adopted. When the catch C is released, the outermost, or "shifting chock," may be shoved outwards and then hinged down out of the way, so that the boat (after letting go the gripes) may at once be shoved horizontally over the vessel's side. Another arrangement is shown in Fig. 5, in which the shifting chock is cast adrift by striking out the dovetailed key K. Very many methods have been proposed and patented, wherein the casting adrift of the boat gripes and outer chocks, so as to leave the boat suspended from the tackles, is accomplished by merely moving a lever or turning a crank, but in the great majority of cases the old-fashioned arrangement just described is preferred, as being sufficiently expeditious, simple, reliable, and free from chances of disorder.

Art. 396. If the **davits** are properly placed and have sufficient outreach, or overhang, the **launching of the boat** between them is a simple matter, so much so, in some cases, as to be almost automatic, *i.e.* assuming the ship to be upright and steady. The operation is simplified and expedited when the davits are placed wide apart, and in high-class passenger vessels they are now usually distant more than the full length of the boats (Figs. 6 and 8, Plate 67). This, of course, is not essential, for the boats may be launched diagonally, one end at a time, as shown in Fig. 7. In many cases, however, the davits are placed inconveniently close together, and if at the same time their outreach should be small, the work of launching may be one of considerable difficulty. In view of this, the boats are sometimes stowed on the outer side of specially constructed davits, fixed or hinged; but this method has met with little favour. In turret-deck steamers ordinary davits are inapplicable, so that here a special type of pivoted davit is employed. In warships the davits are

[1] *Andrew's Patent.*

generally hinged, so that they may be folded down in action, clear of the gun fire.

To control the turning movement of the davits, their heads are guyed fore-and-aft and are connected by a *span*, a purchase tackle being provided for one or both of the *guys*, and sometimes one for the span (Fig. 8, Plate 67). In some cases one of the davits is provided with screw and worm gearing, whereby it may be revolved, and the boat launched, by simply turning a crank.

When a boat is swung outboard, permanently, it is prevented from swinging about with the rolling of the ship, by fixing a fore-and-aft spar (*rolling spar*, or *boat boom*) from davit to davit, and hauling her side in against this by *belt gripes;* and, to prevent chafing, the spar may be provided with pads, or *puddings*.

The **lowering tackles** for large boats have triple-sheave blocks, those for small ones double-sheave blocks. The hauling part, or *fall*, passes from the upper block over a small sheave, or lug, on the side of the davit (Fig. 8, Plate 67), and is lowered away and made fast on a belaying cleat also fixed on the davit. The lower blocks are provided with eyes, which engage with hooks fixed one at either end of the boat; if the hooks were on the blocks they might, after being released, catch the boat by a thwart or the gunwale, and capsize her. When lowering a boat in rough weather, it is very important that both tackles should be released simultaneously, for if only one were let go the boat might be suspended end-up by the other. This disaster may be avoided by the use of a special **disengaging gear.** These vary in design; in the kind usually adopted the ordinary fixed hooks are replaced by slip hooks of special design, so arranged that immediately the boat is waterborne a man, standing in her amidships, may, by simply moving a lever, so alter the formation or condition of the two hooks as to deprive them of their holding power.

Art. 397. The **diameters of boat davits** should, of course, be sufficiently large to avoid all chance of their bending or breaking under the weight of the boat. The bending tendency, or moment, is measured by multiplying half the weight of the boat by the outreach of the davit. If the ship were upright and motionless, and the weight of the boat and contents were known, it would be a simple matter to assign a diameter appropriate to any required margin of strength. But it may happen, when the boats are lowered, that the ship has a considerable list, which, in effect, would increase the outreach of the davits; if inclined 20 degrees, for instance, the outreach (Fig. 8, Plate 67) would be increased by about one-third of the height of the davit, measured from its uppermost point of support. Then, again, if the vessel happened to roll, or rise up and down with the waves, the vertical movement impressed on the boat would result in a virtual increase in its weight, and, in consequence, increase—perhaps very largely—the bending moment on the davits. If affected only by a bending moment, a davit might be regarded simply as a loaded beam, but, of course, besides a bending moment, it is subjected to a direct downward compressive stress, equal to half the weight of the boat. But when the latter stress is taken per square inch of the sectional area of the davit, it is really so small as to be quite negligible, especially in view of the fact that, as the maximum bending stress can only be guessed at, a large factor of safety has in any case to be allowed.

The mathematical formula for the diameter of a solid, round-iron davit is—

$$D = \sqrt[3]{\frac{P \times L}{\cdot 098 \times S}}$$

where D = the diameter in inches;
P = half the weight of the boat in pounds;
L = the outreach of the davit in inches;
S = the stress in pounds per square inch, tensile or compressive, beyond which it is not intended to subject the material of the davit.

The working stress (S in the above formula) for iron is usually taken as 5 tons per square inch, which, if the ultimate strength is 20 tons, gives a factor of safety of 4. If it be taken as 6·12, then the above formula may be written in the simpler form.

$$D = \sqrt[3]{\text{half the weight of the boat in cwts.} \times \text{outreach of davit in feet.}}$$

Lloyd's rules state, that with boats and davits of ordinary proportions, the diameters of the davits should be one-sixtieth of the length of the boat; but where the height and outreach of the davit or the weight of the boat are unusual, the diameters should be computed by the following formula—

$$D = \sqrt[3]{\frac{L \times B \times D}{40}\left(\text{outreach of davit in ft.} + \frac{\text{clear height of davit in feet.}}{3}\right)}$$

where L, B and D = the length, breadth and depth of the boat in feet. Comparing this formula with the last, the weight of the boat will be found to be small, but its arm or leverage is increased by the addition of one-third the clear height of the davit, an effect which, as already seen, would occur if the vessel were inclined 20 degrees from the upright. With davits of exceptional height, it is, of course, very desirable that this feature should be introduced as a modifying factor in the formula.

The results of the application of the foregoing rules, for four different sizes of boats and davits, are given below.

Dimensions of boat.	20′×6′-0″×2′-6″	24′×6′-9″×2′-9″	28′×7′-9″×3′-6″	30′×8′-0″×3′-6″
Number of passengers ...	18	26	45	50
Loaded weight in cwts. ...	30	45	73	86
Outreach of davit	4′–0″	4′–6″	5′–0″	5′–6
Height of davit	9′–0″	9′–0″	9′–0″	9′–0″
Diameter of davit allowing 5 tons working stress ...	4·2″	5·0″	6·1″	6·6″
Diameter of davit allowing 6·12 tons working stress ...	3·9″	4·7″	5·7″	6·2″
Diameter of davit by Lloyd's formula	3·7″	4·4″	5·3″	5·6″
Diameter of davit taken as $\frac{1}{60}$th of the boat's length ...	4·0″	4·8″	5·6″	6·0″

Art. 398. Davits are **tapered** slightly towards the head and heel, but the full diameter must, of course, be maintained from above the uppermost point of support to well on to the curved part. In merchant vessels the taper allowed varies considerably; if made from rolled bars, as is usual, they may only be thinned down close to the head and heel. In **warships** the diameter at head and heel is 60 per cent. of the full diameter; and the section of the curved part is **ovalled**, for this formation, while retaining the necessary strength, permits of a lighter davit (the minor axis of the most

oval section is only from 20 to 25 per cent. smaller than the major axis). Davits may be **forged** from scrap iron, but in most cases they are made from **rolled** iron bars, of special quality, fibrous and free from brittleness. They are forged straight and bent to shape on the slabs, the belaying cleat and lug being welded on afterwards. If there is a sheave, or *cheek block*, it is bolted on. In some cases davits are made of **steel tubing**, there being no taper towards the head or heel.

Davits may be supported in **cast-iron pedestals**, as shown in Fig. 4, Plate 67, or by a **socket and crance**, as shown in Figs. 5 and 8. Cast-iron pedestals are suitable for small davits: they must be massive and strong, and be well bolted to the deck, for, owing to the shortness of the housing of the davit, they may suffer severe stress. When the crance or upper socket of a large davit is fixed to a light boat or shade deck (Fig. 5), diagonal tie plates should be fitted on the beams, converging towards the davit so as to distribute the outward pull. To prevent those davits which sit in shallow sockets from jumping upwards and becoming unshipped, a band or tap bolt is fixed on them under the crance (Fig. 8). A pinching or locking screw is sometimes provided to steady the davit at sea (Fig. 4).

Art. 399. Of **steering gears** there are many varieties, differing more or less both in principle and design. **Hand-power gears** do not vary so much; the kind generally adopted is the well-known right-and-left-hand screw arrangement shown in Fig. 2, Plate 36, in which sleeve-nuts, approaching and receding on a screwed spindle, control, by means of connecting links, a crosshead, fixed on the rudder head. In case of a breakdown of the gear, a supplementary means of controlling the rudder is always provided; if the gear does not embody a tiller (or quadrant) one is fitted, to which *relieving tackles* may be made fast. It is well that provision should also be made for steering, even should the tiller or rudder-head fracture, by fitting an eye or shackle on the upper part of the rudder-bow, from which tackles may be led on deck; sometimes chains, termed "rudder pendants," are connected to this as a fixture, being led up on deck so as to be available at any moment.

All sea-going steamers are provided with **steam steering gear**, and also, in case of a breakdown, with **supplementary hand gear**. The latter is always at the stern, but the steam gear may be amidships, in which case it is connected to the rudder by chains. When the one gear is in use, the other is disconnected from the rudder head. The connection or disconnection may be made in several ways: by moving a clutch, by shipping or unshipping bolts or pivots (Figs. 2 and 5, Plate 68), or by shifting certain parts, or the whole of the steering engine (Fig. 15, Plate 69). The adjustment should be as simple as possible, so that in the event of a breakdown of the steam gear, it may be disconnected and the hand gear coupled up without loss of time. A **breakdown of the operating gear** may leave the rudder, for the time being, uncontrolled and free to swing from side to side, with danger to itself and preventing the coupling up of the other gear. This emergency is often provided against by fitting a frictional brake (Fig. 3, Plate 68), in the form of a moveable block, which may be forced by a screw and lever against the periphery of the quadrant, the surfaces of contact being lined with elm, or formed with interlocking grooves, to increase the friction. If both gears are at the stern, they are always properly housed and sheltered from the weather. If only the hand gear is so situated, it should not be placed on the exposed upper deck, for in heavy weather the stern may be unapproachable, and as it is just in such weather that a breakdown of the steam gear or its connections is most likely to occur, the hand gear, on

account of its inaccessibility (the loss of steering power perhaps rendering it still more inaccessible) might be practically useless. The temporary loss of steering power in heavy weather might, of course, have most disastrous consequences to the ship; and with a view to preventing such a mishap, Lloyd's Register now requires that in vessels over 250 feet long the after steering gear shall be protected by a steel or iron deck house or hood, unless it be elevated on a poop, shelter, or awning deck.

Art. 400. With most steam gears the turning power is conveyed to the rudder-head by means of rods and chains. These might be fixed to the end of a **tiller of single arm type** (Fig. 1, Plate 69), but as the turning power would then vary with the angle of the rudder (becoming zero if the tiller were turned so far as to be in line with the chains), it is made in the form of a quadrant (Fig. 2). A **quadrant tiller** of ordinary construction (Figs. 1, 3, and 6, Plate 68) has a double groove or channel in its curved edge, one for the port and one for the starboard chain. These are fixed to it, the one at one corner and the other at the other, so that while one winds the other unwinds, both, of course, always leaving it tangentially, and exerting, therefore, a constant leverage or turning effect. Although termed a "quadrant," or "quadrant tiller," it is not, in form, necessarily the quarter of a circle, it may be a half circle or even a complete circle. Its actual shape is governed by the direction in which the chains leave it. When the steering gear is forward, they may leave it in an athwartship direction (Figs. 2 and 3, Plate 69), passing round a guide pulley on either side, and thence forward, along by the side of the hatchways or gunwale; in such cases the quadrant need only contain an angle equal to the range of motion of the rudder, *i.e.* about 90 degrees, for then the chains will leave it tangentially at all angles. In many cases, however, the chains lead straight forward (Figs. 4 and 5), and in large vessels the quadrant may then take the form of a complete wheel, perhaps 12 or 15 feet in diameter (Fig. 2, Plate 68). In such a wheel it is only a quadrant-like portion on either side that is really needed, for the chains lie permanently idle on the remainder. In most cases, therefore, instead of a complete wheel, two quadrants are fitted, one on either side (Figs. 4 and 5, Plate 68). A complete wheel possesses superior strength, because, as a pull on the one chain is distributed around its periphery, it affects equally all the arms or spokes. In Fig. 2 there are two grooves or channels on the periphery of the wheel quadrant, but, of course, when the chain leads forward only one is needed.

Quadrants are sometimes made of **cast steel**, in one piece (Fig. 1, Plate 68). More usually, however, the arms and hub are **forged**, the circumferential part being built up of plates and bars. They may be bolted to the rudder head, as in Fig. 4, or shrunk on, a key being provided in either case to secure them against turning should they become loose. When shrunk on, it is an awkward matter to remove them when it is required to unship the rudder, but this necessity seldom, if ever, arises. When large and heavy, their weight is usually supported from the deck by small wheels running on a level path (Fig. 5). Lloyd's rules present a table giving the various sizes of quadrants (forged or cast) suitable for each size of rudder head. The radius of the quadrant is also given, and the corresponding diameter of the steering chains and rods. The latter should, of course, vary inversely as the former, for the greater the radius of the quadrant, the greater the leverage or turning power, and the less the pull required of the chain; accordingly, to suit cases in which the radius adopted differs from that in the table (upon which the tabulated sizes of chain are

based), a formula is given by which the appropriate diameter of chain may be computed.[1]

Art. 401. There are three **positions for the steam steering gear**: at the stern, close to the rudder head, in the wheel house at the front of the bridge, and at the after end of the engine room casing. Each location has its advantages and disadvantages. The first requires steam pipes to be led from the boilers to the stern, and, as the gear must be controlled from the wheel house, a line of shafting from this point aft. As the controlling shafting need only convey the small force necessary to move the steam valve of the engine, it may be of a light description (Fig. 8, Plate 69). The advantage of so placing the gear is that it permits of a direct connection with the rudder head, and avoids long steering chains.

When the gear is on the bridge or in a **'midship wheel house** (Plate 109), as is common in small vessels, chains are required to convey its force to the rudder head. Where the lead is straight, rods take the place of chains (Fig. 17, Plate 69), the latter being used only in way of the guide pulleys (Figs. 18 and 19). They are usually led along by the gunwale, where they are out of the way, small rollers being provided to support and guide the rods (Fig. 10). The links of the chains where they pass over the guide pulleys wear rapidly, the never-ceasing pivoting action causing them to cut into one another, and the pulleys themselves and their axle pins become worn. As a breakdown of the steering chains might be a serious matter, they should be very substantial and be frequently overhauled. Lloyd's rules require the diameter of the guide pulleys to be at least sixteen times that of the chain, for when too small the friction and wear of the chain is excessive Wire rope is sometimes employed as a substitute for chain, but it is usually found to deteriorate rapidly under the constant bending and friction of the pulleys. In vessels which have a poop and bridge house, with a well between, the chains may dip down into the well, over large pulleys, as shown in Fig, 19; but in many cases, to avoid the friction due to these pulleys, the chains—or, rather, rods—are supported on stanchions (Fig. 9), fixed to the bulwark or to the coamings of the hatchways, and are carried over the well at the level of the poop and bridge deck. If placed over the bulwark, they are exposed to blows from the waves, whose force, even at this height, may be sufficient to bend or break them; but with substantial rods and stanchions the contingency is remote. The advantage of so placing the gear is that it dispenses with controlling shafting, and as it is almost over the boilers, the steam pipes have a short and direct lead.

The third position, at the after end of the **engine-room casing**, is the one now most commonly adopted (Plate 110). It involves both controlling shafting and steering chains, but they are short and may have a direct lead. In many cases the engine has two winding barrels, so placed at either side of the casing that the chains may pass directly from it, in a straight line to the quadrant, thus dispensing with guide pulleys and minimizing friction. When so situated, the engine is under the direct observation of the engine-room staff.

In high-class **passenger vessels** the steam **steering gear** is usually placed **at the stern**, for then its noise and vibration are not perceived by the passengers, and there are no clumsy steering chains. As the controlling

[1] $d = \cdot 38\sqrt{\frac{D3}{R}}$

d = the diameter of the chain in inches.
D = the diameter of the rudder head in inches.
R = the radius of the quadrant in inches.

shafting between the engine and wheel house makes little or no noise, it is usually led along a passageway between the cabins, the shaft piercing the beams or having bearings suspended therefrom, as shown in Fig. 8, Plate 69. Sometimes it is placed above the deck, alongside of the steam pipes, but this position is objectionable, for when seas break on deck it is liable to be damaged.

Art. 402. A very ingenious contrivance, known as a "**telemotor,**" has recently come into use, by which the steering gear at the stern is controlled from the bridge by means of two $\frac{1}{2}$-inch copper pipes.[1] These contain water, which, by means of a small pump or hydraulic ram, actuated by the steering wheel in the wheel house amidships, may be made to circulate one way or the other, and by its flow operate a small piston connected to and governing the steam valve of the steering engine. This appliance is usually associated with a type of steering gear known as a "**steam-tiller.**" In this gear the steering engine is fixed upon the tiller and moves with it as one part; it has many unique features, and is often adopted in high-class vessels.

Art. 403. The resistance of the rudder to the turning effect of the steering gear increases the further it is put over to port or starboard, and, accordingly, the greater the angle of the rudder, the greater the force required to work the gear. In some gears this is specially considered, their design being such that their power increases with the angle of the rudder. One of these is illustrated in Fig. 6, Plate 69, and the hydraulic gear shown in Fig. 7 has also this characteristic. It should be observed that the advantage of the increased power is greatly neutralized by the circumstance that it is accompanied by a loss of speed; for it is not often that the rudder is put hard over, and when it is, it is usually in a sudden emergency, when rapidity of action is more important than easiness.

Art. 404. In some vessels the **steering gear** is worked by **hydraulic power.** The usual arrangement, as shown in Fig. 7, Plate 69, is a pair of hydraulic rams, one on either side of a straight tiller, to which they connect by a single block, through which the tiller is free to slide as it swings to port or starboard. When the vessel has other hydraulic appliances on board, there is usually an accumulator in the engine room from which a constant supply of pressure water is obtainable. This is conveyed to the gear by a couple of 1-inch or $1\frac{1}{2}$-inch water pipes, and the steering wheel in the wheel house on the bridge need only actuate a valve, so designed as to admit water to either ram. In modern hydraulic gears this valve is usually controlled from the bridge by a telemotor. In the absence of an accumulator, hydraulic steering gear may be worked by the direct action of a small pumping engine placed in the engine room. A couple of pipes are led from it to the tiller rams at the stern, and, according as the engine revolves one way or the other, so the water is made to flow or circulate along the pipes in either direction, and thus actuate either the starboard or port ram. The pumping engine is controlled from the wheel house like an ordinary steering engine, with which it is, in effect, identical, its power, however, being conveyed to the tiller by water pipes instead of by chains. A rather serious objection to hydraulic steering gears is the chance of the water being frozen in cold weather.

Art. 405. In order that the precise **angle of the rudder** may be known to the steersman in the wheel house, it is usual, in high-class vessels, to provide a "**tell-tale.**" This is simply a small-linked chain

[1] A description of this contrivance will be found in Mr. Betts Brown's paper in the *Trans. Institution of Naval Architects*, 1890, in which he also describes his patent "*Steam-tiller*," Hydraulic Derricks and Cranes.

(such as is used for the mechanical telegraphs between the bridge and engine room), which passes round the rudder head, and thence to the wheel house, where it actuates a small arm representing the tiller or rudder.

Art. 406. When the rudder is struck violently by a wave, it is very desirable that **it should give or yield to the blow.** If rigidly held by the tiller or steering gear, the resulting stresses on its frame, pintles, crossheads and quadrant, also those transmitted to the steering gear, chains, etc., might be of so concussive a character as to cause rupture of one or other of those parts. With hand gear, the desired cushioning effect is not usually provided, but with steam gear it always is—Lloyd's rules now require it. When the gear connects by chains to the quadrant, the plan usually adopted is to introduce, somewhere in the port and starboard chains, a **spring buffer** in the form of a spiral spring (Fig. 17, Plate 69). It will be noticed that the pull of the steering rod puts the spring in compression; this is advantageous in that, should the spring break it will not part, and will still act as a buffer. As regards the efficiency of a spring for this purpose, there are some points to observe. It is important that the rudder should only yield to a force exceeding in intensity that which would occur if it were put hard over with the vessel going full speed, for if it yielded to a smaller force the steering qualities might be prejudiced. Now, to stretch or compress a spring requires a variable force—zero to begin with, and increasing more or less rapidly according to the strength of the spring; if, therefore, the springs introduced in the steering chains were in their normal state, the rudder would not promptly obey the impulse of the gear, because, however small the force applied, the particular spring through which the force was conveyed would have to be compressed before it could move the rudder. To avoid this, the springs must be in initial compression. The contrivance which is commonly adopted and which secures this result is shown in Fig. 17, in which A and B represent the steering rods, whose pull compresses the springs, and N the nut controlling the initial compression. Another similar appliance is shown in Fig. 16. In some cases blocks of india-rubber are substituted for springs, but these have little give, they serve merely to reduce the concussive and jarring effects. The buffers are usually carried on wheels, a slide being provided, usually in the form of a wooden trough or channel bar. It should be observed that a certain amount of tautness in the steering chains is advantageous in reducing the wear and tear of the links and pulleys, for it prevents side play and vibratory movement, with its wearing effect; and, accordingly, to keep the chains taut, each one is provided with a tightening screw.

When the steering engine is located at the rudder head, it may be geared to it by a small pinion wheel, engaging with teeth on the periphery of the quadrant (Fig. 15, Plate 69). This arrangement permits of a very neat adaption of the above-mentioned spring buffers. Here the quadrant works loosely on the rudder-head, and an ordinary tiller, keyed to the latter, is placed immediately above it; if now the quadrant were connected to the tiller it would, in effect, be fixed to the rudder head, and this connection is made, but through the medium of two spiral springs, as shown. One of these springs is shown in Fig. 16; excepting a modification in the connection of the rods, the arrangement is the same as that shown in Fig. 17; but the modification secures an important effect, for it will be observed that whether the rods A and B push towards one another or pull asunder, the spring becomes compressed; that is to say, whether the quadrant in Fig. 15 moves to port or starboard, it tends to compress both springs,

but, of course, does not actually do so unless a certain force—regulated by the nuts N—is exceeded.

In some high-class gears the steering engine is geared directly to the rudder head or quadrant by a **frictional coupling**, which slips should a certain force be exceeded; and the engine is so arranged that whatever the movement of the rudder during the slipping, it will at once bring it back to its original position. This refinement is a feature of the steam-tiller already mentioned. The cushioning effect is here very excellent, for, excepting the constant retarding force of the friction, the rudder, when struck a violent blow, is free to swing round through any angle. The spring buffers just described permit of only a small movement.

CHAPTER XXVIII.

Art. 407. As a general rule, the watertight bulkheads of merchant vessels cut off entirely the adjoining compartments, so that to pass from one to another a man must go on deck and descend by the hatchways. A direct communication may be established by fitting **watertight doors** in the bulkheads, and this is frequently done, but only in special cases, where the convenience of direct communication is particularly desirable. Bulkhead doors are objectionable in that the integrity of the bulkheads is then dependent on circumstances, some of which may not always be under control. The keeping of them in good working order, for instance, and the shutting of them promptly in moments of danger, are matters which depend on the care, intelligence, and smartness of the crew, qualities which, of course, are variable and uncertain. But apart from this, the catastrophe which calls for the shutting of the doors may also make it impossible; for even the most efficient door may be damaged or jammed by obstacles thrown against or through it by a sudden rush of water.

Watertight doors vary in their design according to their purpose and position in the ship. The simplest kind is merely an opening cut in the bulkhead, over which, when not in use, a plate is securely bolted. Properly speaking, this is a shutter rather than a door, but it is generally referred to as a **"detachable"** or **"portable plate."** It is employed in cases where a passage through a bulkhead is only required in harbour, to facilitate loading operations or the repair and overhaul of the machinery; before the vessel puts to sea the plate is rebolted, and may not be removed again for a long time. If used legitimately it is a safe kind of door, but unfortunately it is not always so used; it is common, for instance, for the replacement of the plate to be neglected, those in charge—perhaps a new crew or new owners—finding a permanent passageway a convenience, and not realizing that it means the abandonment of a bulkhead, and the serious consequences that this may involve.

Detachable plates are often fitted in the machinery bulkheads, to give space for the removal of contiguous parts of the machinery, such as the fore-and-aft withdrawal of the condenser tubes. They are also sometimes fitted in the bulkheads separating the 'tween-deck coal bunkers from the contiguous 'tween-deck cargo space, so that coal or cargo may be passed from the one space to the other. In sailing-ships one is sometimes fitted in the upper part of the collision bulkhead, so that logs of timber may be loaded or discharged, end-on through a bow-port cut in the side near the stem. In making them, care should be observed that the strength of the bulkhead against bursting pressure is maintained; if stiffeners are severed they should be made good, and the edges of the doorway should be stiffened by a frame. The joint is usually made with putty and rope yarn, and to ensure watertightness the bolts should be closely spaced. Sometimes, instead of loose bolts, studs are fixed in the bulkhead, for there is a chance of loose bolts being omitted.

Art. 408. To facilitate the removal of a portable plate, it may be **hinged**, when, of course, it at once becomes a **door**. If it is only intended to be opened in harbour, it may, as before, be secured by bolts, and if the hinges are properly made it is then a cheap and secure door. In some cases, instead of bolts, small *clamps* are employed (as in Fig. 8, Plate 72), but these are less secure than bolts. A high-class hinged door, which is intended to be used at sea, is shown in Fig. 3, Plate 70. It is closed by means of *lever clips*, *turnbuckles*, or *latches*, which, by engaging with the wedge pieces, pull the door tightly home against the bulkhead. A watertight joint is secured by the rubber strips fitted all around the door, which is pressed by the action of the clips against the projecting flange of the frame riveted around the doorway. The door itself should be stiffened by a light angle, or heavy flat-iron, frame, so that the binding effect of the clips may be distributed; and as these, in the event of the door being subjected to water pressure (in a direction tending to open it), may have the whole work of keeping it shut, and as they are subject to rough usuage, they should be massive and closely spaced. If the door is only opened and closed from one side of the bulkhead, the clips, of course, need only be fitted on that side. The hinges cannot be made to serve as clips, and their pin-holes must be oval (in one part), so that the clips may move the door laterally against the bulkhead and compress the rubber. There should be no discontinuity in the rubber strip where jointed at the corners, and as it is apt to stick to the part of the frame against which it is pressed, and tear when the door is opened, it should be fixed on both edges, by double strips of iron, secured by brass screws.

Hinged doors ought not to be fitted on the lower part of a bulkhead, for a sudden inrush of water might not give time to shut them properly, and they are not suited to withstand a large head of water. They are suitable for the upper 'tween deck portion, to give communication if necessary between contiguous coal-bunker or cargo spaces. They are also very commonly fitted in passenger vessels, to give fore-and-aft communication between the 'tween-deck cabin spaces, otherwise separated by bulkheads. Here they are practically always open, but although, in case of collision, there would be no difficulty in closing them, it might be impossible to do so should a **fire** break out in their vicinity; and in view of this it is now common, in high-class passenger vessels, to employ, in every case, sliding doors, geared to the upper deck.

In one kind of hinged watertight door the usual clips are dispensed with, their place being taken by sliding locks, which may be worked simultaneously (like those in the door of a fire-proof safe) by a central hand wheel or lever. The advantage here is the speed with which the door may be fastened after shutting, the one movement operating all the locks. The clamping effect of the locks, however, is small compared with that of ordinary clips, for the effort of the man who shuts the door, instead of being concentrated at each one separately, is applied simultaneously to them all.

Art. 409. Watertight doors which are situated below water, and which are used at sea, must be geared upwards, so that they may be closed from the upper deck or a deck well above water, for a sudden inrush of water might prevent access to the door. **Geared doors** are of sliding pattern, their movement being controlled from the upper deck by a vertical shaft (Figs. 1, 4, and 5, Plate 70, and Figs. 5 and 6, Plate 71). They may slide vertically or horizontally; as regards efficiency, there is little to choose between the two types. Vertical doors are specially suitable for coal bunkers, and as they are lighter and cheaper they are generally

preferred; but they cannot be placed between decks, or elsewhere where there is little head room.

Vertical doors are usually operated by a screwed shaft, which works through a nut fixed on the door (Fig. 4, Plate 70, and Fig. 5, Plate 71); otherwise, a rack and worm may be substituted (Fig. 6, Plate 71). Horizontal doors are worked by rack and pinion gearing (Fig. 1, Plate 70). In a vertical door, each revolution of the shaft raises or lowers it only by the pitch of the screw thread, *i.e.* from $\frac{1}{2}$ to $1\frac{1}{2}$ inches; whereas the corresponding movement of a horizontal door is equal to the periphery of the pitch circle of the pinion, or about 12 or 15 inches; and, moreover, a horizontal door need only be moved through a distance equal to the breadth of the doorway, instead of the height, as in a vertical door. A horizontal door may, therefore, be more quickly closed than a vertical one. The movement of a vertical door may be accelerated by increasing the pitch of its screwed shaft, but with a shaft of fixed diameter this is limited, for if very great the thread would be so inclined as to make it impossible, on account of excessive friction, to lift the doors. Of course, as regards the closing movement, a large angle of thread is advantageous, for the door may run down quickly almost by its own weight, turning the screw Archimedean-drill fashion. While maintaining a suitably small angle of thread, however, the pitch may be increased by simply increasing the diameter of the screwed shaft; if a very quick movement is desired, a hollow shaft may be employed, 3 or 4 inches in diameter. As fitted in high-class doors, the shaft is always large, usually about $2\frac{1}{4}$ inches diameter, with a pitch of about $1\frac{1}{2}$ inch, and as a single small thread would leave a wide space between each of its convolutions, there are three separate threads. In the door shown in Fig. 6, Plate 71, the worm is practically a screwed shaft of very large diameter and pitch, which carries with it the advantage, just noticed, of a rapid movement of the door; on the other hand, it is a less perfect mechanical contrivance, for it causes side pressure and friction.

Geared watertight doors vary greatly in the details of their construction and the general efficiency of their design. In those fitted in ordinary merchant vessels, cheapness of construction is often more studied than efficiency, and in many cases they are not even approximately watertight. Those fitted in warships are designed and constructed with the greatest care, so as to combine lightness with the maximum of efficiency, strength, and endurance; and, of course, they are perfectly watertight.

Art. 410. A **horizontal door** such as is fitted in warships and high-class merchant vessels is shown in Fig. 1, Plate 70. The frame F is of cast-iron, and as it may warp during the cooling, and as the bulkhead to which it is bolted is never a perfect plane, it is cast with projecting *fitting-strips*, S, which, being narrow, may be chipped readily by hand to fit over, and conform to, the irregularities of the bulkhead. To save weight and material, it is cut away between the bolts, as shown at S, Fig. 4. The guide grooves for the door are formed by the flat, wrought-iron face pieces P, which, while secured by the same bolts that hold the frame to the bulkhead, can be taken off without disturbing the latter, thus facilitating the planing and scraping of the contact surface in the groove. The top and bottom grooves, and the corresponding edges of the door, are slightly tapered, so that when the door is closed it may be pressed into watertight contact with the cast-iron frame. When the door is open, the thin part of its edge is in the wide part of the groove, and, to prevent it from jarring at sea, a small parallel groove, Q, is provided at the bottom of each tapered one. The door itself may be a steel plate or casting, and small doors are sometimes of cast brass. The one shown in Fig. 1 is a steel plate; around its

margin, where, when closed, it presses with watertight contact against the cast-iron frame, parallel strips of brass, R, are riveted, and these and the frame are carefully machined so as to form perfect planes and fit accurately upon one another. To provide for the wedging action, similar, but tapered, strips, E, are fitted on the opposite surface of the door, which, of course, when the door is closed, take contact with the face pieces, P. The back vertical edge of the door, has, of course, no groove to enter, but it is pressed against the cast-iron frame by the shaft, this being accomplished by locally increasing the projection of the racks, so that, when the door is closed, the pinion wheels may press against it at that part. To reduce friction, horizontal doors are often provided with a couple of small wheel casters.

Art. 411. A high-class **vertical door** is shown in Fig. 4, Plate 70. The frame, as before, is of cast-iron, with wrought-iron face pieces, but another method of construction is illustrated for the door itself. This is a steel plate, but instead of fitting, as in Fig. 1, separate face and wedge strips of brass, marginal pieces of cast brass are provided. Here isolated projections, W, take the place of a continuous tapered strip. These are advantageous in that they reduce the weight, and, owing to the smaller surface requiring planing and adjusting, facilitate the fitting of the door; further, should their surfaces become clogged with dirt, the circumstance is less likely to prevent the complete closing of the door. In a vertical door the wedging action only takes place at the sides, but as the door is well stiffened across the top and bottom, sufficient pressure is transmitted across it. The nut through which the shaft works is of gun-metal. The construction and fitting of these light, high-class watertight doors is not a simple matter, for although, after carefully planing, filing and scraping the sliding surfaces, the door may work with perfect precision and closeness of fit in the shop, the subsequent fitting and bolting of it to the bulkhead may so strain it as to destroy the accuracy of the work, which must then be corrected by further filing and scraping.

Art. 412. The **geared doors** commonly fitted **in merchant vessels** are of cast iron (Fig. 5, Plate 71), and, if carefully designed and fitted, they may be perfectly efficient. To avoid chipping the frame, so as to make it fit the irregular surface of the bulkhead, a thin backing of hardwood is sometimes introduced; fitting strips, if provided at all, are usually too shallow to chip. Wood packing simplifies the fitting work, but it is objectionable in that should the bulkhead be called upon to act as a fire screen, it might burn and loosen the door; but of course, it is probable that before the hardwood between the two metal surfaces was burned away, the bulkhead would itself have become red hot and spread the fire to the cargo in the next hold. Sometimes, instead of fitting wood backing, liquid lead is run in between the frame and the bulkhead. This fills all interstices and makes a solid job, but it is objectionable in that, should a fire occur, the lead would at once melt and leave the door loose. In the door shown in Fig. 5 there is no parallel groove corresponding with that shown in Fig. 4, Plate 70, so that when the door is open it fits loosely in the tapered groove and may rattle continuously at sea. This is a serious matter, for not only does the continuous hammering injure the sliding surfaces, but the engine-room staff, to stop the noise, usually jam a piece of wood between the upper part of the door and the bulkhead, an expedient which at once makes it impossible to close the door from the deck, and sometimes even from below, for to remove the obstruction, when the door is tightly jammed, may be awkward and tedious.

Art. 413. In practically all screw steamers there is at least one watertight door, viz., that which gives access to the tunnel. And in modern

cargo vessels there are usually two more, in the bulkhead separating the boiler room from the fore hold, so that when the after part of the latter is used as a bunker, the coal may be available to the stokehold. These doors are practically always of vertical type. **Watertight doors** which give access to a **coal bunker** are always objectionable, and they should, therefore, be avoided, if practicable, by so designing the coal bunkers that the containing wall next the stokehold is not a watertight one. There are three objections to these doors: (1) the coal dust, sticking and clogging in the oily grooves, may prevent the door from shutting close; (2) the cast-iron surfaces may become so worn away by corrosion and attrition as to destroy all watertightness; (3) should it be required suddenly to close the door, its opening may, just at that moment, be obstructed by large lumps of coal, or coal may be washed through it by the in-rushing water.[1] The first two objections may be met by carefulness on the part of those in charge. The last is not so easily avoided, but it may be, in great measure, by fitting a screen behind the door, as shown in Fig. 8, Plate 71, which, it will be observed, keeps back the coal, so that when the bunker is full it may not lie heaped up against the door, nor tumble out and obstruct the opening when the door is opened. This provision is always made in warships. Sometimes the lower edge of the door is provided with a sharp knife edge, so that it may cut through minor obstructions. Bunker doors are usually about 3 feet high, by 2 feet wide, but when the bunkers are large and are so situated that, to work the coal, men must pass through the doorways with wheelbarrows, they must be considerably larger.

When watertight doors are placed within a coal bunker (as is common in the bulkheads subdividing the 'tween-deck bunkers of large vessels) **protecting screens or casings** are sometimes fitted, as shown in Fig. 9, Plate 71. In their absence, the coal (when the bunker is full), by pressing against either side of the door, would prevent it from being either opened or shut. When a vertical bunker door is open, and coal is being passed through it, its screwed shaft may become so clogged with coal dust as to prevent its working through the nut; this is avoided in high-class doors by providing a tube or sheath to cover and protect the screw when the door is open (see Fig. 4, Plate 70). The lower groove of a horizontal bunker door, if not covered when the door is open, would become filled with coal dust, which, of course, might prevent the shutting of the door. This may be provided against to a certain extent by leaving openings in the cast-iron frame at the bottom of the groove; but in high-class doors, whether situated in a bunker or elsewhere, the more thorough provision is made of fitting an **automatic sill-plate**, as shown in Fig. 7, Plate 71. This is so pivoted and weighted that immediately the door is opened it falls down and covers the groove; and it does not prevent the closing of the door, for it is raised and tipped over out of the way by the door itself, the leading edge of which takes contact with its bevelled end, B, and wedges it over as shown by the dotted lines in the section. Vertical doors have no lower groove, and in this respect they are preferable to horizontal doors, especially for coal bunkers.

Art. 414. The **controlling shaft** of watertight tunnel and stokehold doors is led to the upper part of the engine room or stokehold, and is worked there by a wheel handle, or cross bar (Fig. 6, Plate 71); the latter may be fitted loosely, as in a vice, but a ratchet handle is better, in that it permits of greater speed and precision, and gives ample power. When the controlling shaft passes through the deck, it terminates in a brass **deck plate**, the top of which when unscrewed exposes the end of the shaft,

[1] The loss of the s.s. *Oregon* is attributed to a circumstance of this kind.

which is squared to take a T-shaped spanner (see Fig. 5, Plate 70). As fitted in merchant vessels, the deck plates do not usually indicate the position of the door, and sometimes there is not even an arrow to show the direction of the opening or shutting movement. In warships and high-class merchant vessels special **indicating deck plates** are provided, from which the position of the door may be seen at a glance, by the position of the arrows engraved on the deck plate (Fig. 5). In merchant vessels the watertight doors are not usually arranged to work from below; in warships they may be worked both from below and above. With a vertical door this is accomplished as shown in Fig. 5, Plate 70, by means of a couple of bevel wheels, a sprocket wheel, and an endless chain. If the chain is pulled smartly, the door may be closed in a few seconds. A similar arrangement may be applied to horizontal doors, but the more simple plan is usually adopted of enlarging the hub of one of the pinion wheels, and providing it with spoke holes for the insertion of a lever bar (Fig. 1). In warships the controlling shaft has seldom a direct lead to the upper deck, so that bevel-wheel gearing is extensively employed. All such gearing is of the most perfect description; the bearing brackets are of cast steel, each one designed to suit the peculiarities of its particular position; all the bevel and pinion wheels are of gun-metal, and all journals are bushed with brass.

Art. 415. Much of the objection to watertight doors would disappear if the closing of them could be accomplished with great speed and little effort, for if delayed it might become impossible. And it would be still further nullified if some simple arrangement were adopted whereby the doors would close automatically in the event of water rising up towards their sills, for then even the omission (on the part of the crew) to close them would not prove disastrous. A large number of so-called "**quick-closing**" and "**automatic gears**" have been proposed and patented, but very few have been found sufficiently simple and free from objections to warrant their adoption. They are applicable chiefly to vertical doors, and the governing principle of their design is usually some mechanical arrangement (workable both from the deck and below) whereby the ordinary gear may be uncoupled, so that the door, being free, may fall at once by its own weight; if it fell suddenly, however, something would probably give way, and to avoid this, therefore, its motion must be modified or controlled by a counter-weight, or by some form of brake. Automatic closing gears usually embody a buoyant float, which is placed at a lower level than the sill of the door, so that should water enter and buoy it upwards, it may—by suitably attached levers—free the door from the restraint of its ordinary gear and allow it to drop by its own weight. In some high-class passenger vessels the vertical doors are worked by hydraulic power, a hydraulic cylinder being fixed above the door, which is pulled up or pushed down by a piston-rod. Hydraulic power is very suitable for this work, for the doors may be worked quickly or slowly by simply moving a valve handle; and the mechanism may be so arranged that after any one has opened the door and passed through, it will close the door again, gradually and automatically.[1] In many cases electric motors are advantageously employed for closing the doors, and arrangements are sometimes made for controlling the movement of each one from the bridge.

In practice quick-closing and automatic gears are rarely adopted, for, apart from the question of cost, they usually involve extensive and elaborate

[1] Illustrations and descriptions of a large number of quick, and automatic closing gears, and of different kinds of watertight doors, will be found in Mr. Martell's paper in the *Trans. Institution of Naval Architects* for 1897.

mechanism, which, although it may do, when in good order, all that is claimed for it, is not unlikely to be found unworkable at the unexpected, critical moment; for owing to long disuse it may get out of order, or the men may bungle in working it. The attitude of the men, moreover, is against their adoption; thus, when at sea, men are constantly in the shaft tunnel attending to the bearings, and in the coal bunkers trimming coal, and if they knew that, in a moment of danger, they might be imprisoned by the sudden closing of the doors, or be crushed by them when in the act of passing through, they would assuredly take steps to prevent the occurrence, by simply jamming the doors open—a serious matter, in that it would then be impossible to close them from the deck, and perhaps even from below. To meet the case, special vertical escape shafts might be provided, but it is unlikely that these would prove quite satisfactory to the men. For these reasons quick-closing gears are rarely adopted either in merchant vessels or warships. In the latter there may be as many as 20 or 30 large geared doors, but all are worked with the ordinary screw, or rack and pinion gear; for practical purposes, however, these may be regarded as quick-closing gears, for the doors may be shut by them in considerably less than 30 seconds. They are simple to manipulate, they cannot get out of order, and the men are trained daily in using them.

Art. 416. Watertight manhole covers, such as are fitted on tank tops, vary considerably in design; some different kinds are shown in Plate 72. Watertightness is usually secured with putty and rope yarn. Figs. 1 and 2 represent old-fashioned arrangements. The cover shown in Fig. 8 is one very commonly adopted. That shown in Fig. 4 is advantageous in that there are only two nuts to tighten, and the cast-iron segmental cap protects the cover. Figs. 6 and 10 show arrangements sometimes adopted where there is no ceiling planking; if, in such a case, an ordinary manhole door were employed, an angle frame would have to be riveted to the tank top, to secure the cover necessary to protect the bolts from being struck and broken or loosened by cargo. Fig. 11 shows the arrangement commonly adopted in warships; it is costly, and has no particular advantage, and the coaming makes it rather more awkward to pass through the hole. It will be observed that, with the exception of the covers shown in Figs. 2, 7, and 11, all the others have the important advantage that they are fitted below the tank top, so that the water pressure assists the bolts in forcing them tightly on to their seating. Watertight hatch covers, such as are fitted over deep tanks, are described in Art. 367, and illustrated in Plate 71.

CHAPTER XXIX.

Art. 417. As all vessels are liable to make water, **pumps** must be provided to clear it away, not only for the safety of the ship but to avoid the damage which cargo might suffer should even a small volume of water wash about at the bottom of the hold. A well-built steel or iron ship may be said to be as tight as a bottle; if the hatches, etc., are tightly battened down so that no water can pass through them, the pumps need never be used. Large wood ships often leak so freely as to require almost continuous pumping, and, to save manual labour, the pumps of old vessels are usually geared to a portable windmill arrangement, so that they may be worked continuously and automatically.[1] But although under normal conditions a well-built steel or iron ship is usually quite tight, there is still always a possibility of water entering, for she may spring a leak, through starting of the seams and riveting of the shell, due either to straining in heavy weather or to striking sunken wreckage; and volumes of water may pour through the hatchways or other deck openings if these should be ill-secured in heavy weather; and, of course, collisions and strandings, though unlikely occurrences, may cause serious leakage.

In steamers water always tends to accumulate in the **machinery compartment**, through leakage from the various drain cocks, pumps and cisterns, and the constant flow into the bilges of the water used for cooling the bearings and extinguishing the hot ashes in the stokehold. To clear this away, steam bilge pumps are kept more or less constantly in operation. The machinery compartment is also liable, in heavy weather, to downpours of sea water through the fiddley gratings and ventilators, kept open to supply air to the furnaces and to ventilate the hot spaces below. To provide against this, the machinery openings are raised well above the upper deck, by means of casings (Art. 219); in large passenger vessels, with their high freeboard and lofty promenade and shade decks, they may be 30 or 40 feet above water. It may be observed that when waves break over a ship they have a surprising power of leaping upwards; in exceptional cases even the side rails of so lofty a structure as the flying bridge are sometimes bent and broken by blows from solid water; the wheel house may be stove in, and the funnel and stokehold ventilators swept away.

Should a large volume of water accumulate in the **machinery bilges**, the result might be serious, for, as noticed in Art. 249, it may, in washing from side to side, lift the stokehold plates and throw them about to the danger of pipes and valves, it may also, by washing coal and ashes into the bilges, result in the **choking of the pumps**, and, with these inoperative, the water might accumulate, extinguish the fires, and ultimately cause the loss of the ship. The danger of a sudden accumulation of water in the machinery bilges is best met by providing ample bilge space below the

[1] An automatic system of pumping and ventilating (*Thiev's*) wherein the rolling movement of the ship is utilized as prime mover, was applied to some of the early warships.—See "*Naval Science*," vol. 2, 1873.

platforms. In a double-bottom vessel the stokehold plates may only be a foot or two above the tank top, in which case, with only the side gutters to contain bilge water,[1] a comparatively small quantity might roll over the tank top, with the results just noticed. To avoid this, therefore, it is usual to provide a large pump well in the machinery compartment (Fig. 2, Plate 18, and Plates 109, 110), for, of course, until this fills, water cannot rise above the tank top. The plan now often adopted of discontinuing the double bottom under the boilers is an excellent one as regards the providing of a capacious well.

The **pumping arrangement** of a **cargo vessel** is a simple affair; that of a **large passenger vessel** may be complicated and extensive; in **warships**, owing to their numerous watertight compartments and special requirements, it is intricate in the extreme. **Sailing-ships** have only a pair of large hand pumps, but if a steam winch is carried, it is usually arranged to gear by messenger chain to the pumps. Steamers are provided with both hand and steam pumps; the former are usually worked from the deck; the latter, of course, are in the engine room, suction pipes being led from them to the various holds. In large steamers, having ballast tanks, there are two steam pumping systems: *bilge pumps* for the holds, and *ballast pumps* for the tanks. All steam pumps, however, are so connected by piping as to be available together or separately for either service.

Art. 418. The **bilge pump**—or pumps, for they are practically always in duplicate—is geared to and forms part of the main engine, so that, of course when this is not working, the pump is inoperative; in order, therefore, that steam pumping power may be available at all times, an independent steam **donkey pump** is always provided; and in practically all steamers there is a donkey boiler to provide steam for this donkey pump, and for other auxiliary machinery, in port, when the main boilers are cold (Art. 230). The donkey pump connects to the same system of piping as the bilge pumps, so that both may do the same work together or separately. The bilge pump is arranged to draw water from every compartment in the ship; there are thus numerous pipes leading to the pump, but as there is only one in actual connection therewith, a special union is necessary whereby the pumping power may be distributed as required. This is accomplished by means of a **valve chest**, which, as shown in Figs. 11 and 12, Plate 74, is a rectangular, cast-iron box, to which the pump suction[2] and the various branch suctions connect. In the chest, over each branch, there is a *screw-down valve;* if all of these are closed, the chest forms a *cul-de-sac* for the pump suction, and, of course, any one that is opened at once forms a continuation of it. On each valve handle there is marked the compartment which it controls, and, by opening any particular one, any particular hold may be pumped from.

Separate valve chests are provided for the forward and for the after holds, and as the connection to the pump is made by a single pipe, the total length of piping is minimized by placing the former in the forward stokehold and the latter at the after end of the engine room, where, of course, they are always accessible. To save piping, there are usually two or three chests for each region. As already mentioned, the donkey pump is also available for pumping the bilges; and in large vessels there is a separate ballast pump for the ballast tanks, and a fire-engine pump, and all these have a connection (direct or indirect) to the bilge valve chests, so

[1] The term "bilge water" is used in referring to any free water in the holds; a small quantity of water in a ballast tank is not properly so termed.

[2] The term "suction" is used to denote any pipe through which water is *sucked* by a pump.

that all the pumping power of the ship (excepting the circulating pump) may be brought to bear on any particular hold; but, of course, in order that this concentration of power may be useful, the suction pipes to each hold must be exceptionally large or numerous. The number, size, and disposition of the suction pipes to the various holds varies according to the size of the vessel, the character of the hold, and whether or not there is a double bottom. Lloyd's rules specify certain requirements, and as these represent modern practice, they will be specially considered in the following.

Art. 419. Notice, first, the **arrangement of pump suctions** in a vessel not having a double bottom. In the 'midship holds of a large flat-bottomed steamer three steam suctions are provided, one over the keel and one at either side, near the bilge (see Fig. 30, Plate 73). The necessity for the latter is indicated in the sketch, in which the vessel is depicted as having taken a list, and the bilge water as having run down out of range of the centre-line suction; if there were no side suctions, the water, not being under control, might increase in volume and, by heeling the ship still further, perhaps capsize her. In holds towards the bow and stern, or in 'midship, sharp-bottomed holds, suctions are only required over the keel, two in large holds and one in small. In the 'midship holds of small flat-bottomed vessels two steam suctions may suffice, one towards either bilge; or if sharp-bottomed, one centre-line suction. The diameters of the bilge-suction pipes depend on the size of the vessel, and whether there are one, two, or three in a hold. The general practice, and that specified in Lloyd's rules, is 2-inch piping for vessels less than 500 tons, to $3\frac{1}{2}$-inch for those over 3000 tons. The centre-line suction is usually from $\frac{1}{2}$ to 1 inch larger than those at the sides, the latter being regarded as auxiliary or emergency suctions. In case a vessel should make water when lying in harbour with no steam in the boilers, hand-pump suctions are provided to every hold. Each of these may be connected to a separate lift pump on the upper deck; but in modern vessels a single Downton pump is usually substituted, in which case special hand-pump suction pipes may be dispensed with, the steam-pump suction pipes serving both purposes.

Special **pumping power** is always provided **for the machinery space**; for not only is water particularly liable to accumulate here, but the suction pipes are apt to be choked by the coal dust, ashes, grease, bits of waste, etc., which always gather in the machinery bilges. Coal dust and grease form together a stiff paste (which forms into balls with the rolling of the vessel) which quickly chokes the limber holes in the floors, so that water cannot pass freely to the pump suctions; to provide against this, therefore, it is common to pass a small chain through the limber holes, from end to end of the machinery space, which, when pulled backwards and forwards occasionally, keeps the holes clear.

Not less than three bilge suctions are fitted in the machinery space, one over the keel and one at each bilge, connected usually to the valve chest controlling the after holds. And, further, Lloyd's rules require an **independent suction**, having a direct lead **from the donkey pump**; this is useful in that, being controlled by a single valve, it may be put in operation without delay, independently of other pumping work going on through the valve chest common to the numerous hold suctions, and, therefore, with comparative freedom from breakdowns due to leaky or shocked valves. And, as a further means of rapidly removing, in an emergency, large volumes of water from the machinery bilges, the **circulating pump** has a special suction leading into them. This pump is worked by the

main engine, but in some cases it is driven by an independent engine, sometimes of centrifugal type. Its duty is to draw water from the sea through a large under-water valve, inject it into and through the condenser (so that it may circulate among the steam tubes), and finally eject it through a valve in the vessel's side, above the load-water line. As a large volume of water is required to cool thoroughly the condenser tubes, the circulating pump must be large and powerful; and it is evident, if it be made to draw its supply of water from the bilge instead of from the sea, that, while still cooling the condenser, it would do the additional useful work of rapidly clearing away the bilge water. Its bilge suction pipe, or "*bilge injection*," as it is termed (referring to the injection, *into the condenser*, of *bilge* water instead of sea water), is led down to the tank top or into the side gutter, where it is readily accessible for examination and clearing.

Art. 420. In a vessel having a **continuous double bottom**, the only place wherein bilge water can accumulate is the **side gutters.** Compared with the bilge space existing with ordinary floors, the capacity of the side gutters is, of course, very limited; but as the chance of serious leakage is small, bilge water may be kept quite sufficiently under control by fitting, in each gutter, a steam suction (Fig. 13, Plate 73). Nevertheless, it is often thought desirable to increase the bilge space, so that should a considerable volume of water accumulate from some abnormal cause, it may not, before it is pumped out, fill the gutters, wash over the tank top and damage cargo. This is accomplished by forming **wells** in the double bottom, by fitting two watertight divisions—*i.e.* making two of the floors watertight—in place of one, at the end of each tank, and piercing holes in the margin plate so that the water in the gutters may flow into the well (Fig. 2, Plate 18, and Figs. 7 and 12, Plate 88). Wells are advantageous not only in increasing the bilge space, but because, as the water from both side gutters accumulates in one compact mass, it may be controlled by one pump suction and sounded in one operation. They are objectionable, however, in that, forming discontinuities in the double bottom, they destroy its valuable character as a complete, watertight, inner skin, and as they are confined and not readily accessible, they are apt to be neglected and to become choked with mud, which in some cases may result in serious local corrosion. For these reasons it is usually preferred not to provide wells in a double bottom, excepting, however, in the machinery space, where, as already noticed, a large bilge space is exceedingly desirable. In cargo holds the wells are usually only one frame space in length, but in the machinery space not less than two. In the extreme forward and after holds there is sometimes a natural well, due to the double bottom terminating a short distance from the forward and after-peak bulkheads.

Sometimes the special advantage of a well is secured without interfering with the completeness of the watertight inner bottom, by fitting at each opening into the well through the margin plate or tank top, a *non-return valve*, *i.e.* a valve which, while permitting water to pass into the well, closes automatically, should it seek to pass the other way—from the well into the hold (see A, Fig. 2, Plate 18). Valves of this type, though largely used in warships, are rarely employed in merchant vessels; when situated in the bilge, where dirt rapidly accumulates, they are not at all reliable. Sometimes, in place of carrying the well right across the tank, it is confined to the central part lying between the two innermost longitudinals (Fig. 4), and in order that water may drain into it from the gutters, large wrought-iron conduit pipes, with or without non-return valves, are fitted between. When the tank top slopes upwards towards either bilge, any drainage water which collects upon it flows naturally towards the centre line instead of

into the side gutters; here, therefore, wells should be fitted with drain holes in the tank top. To preserve, in such cases, the integrity of the tank top, the well is sometimes formed as a *pocket* or recess, a single pump suction being led into it to remove drainage water (Fig. 3).

The arrangement of the bilge suctions in a vessel having a double bottom depends on whether or not wells are provided. If there is no well, a steam suction is placed in each gutter; if there is one, and the vessel is flat-bottomed, another is fitted over the keel, in the well; if sharp-bottomed, the latter alone may suffice. In the machinery space, if there is no well, two steam suctions are fitted in each gutter; if there is a well, one is fitted in it, and one in each gutter, where it is readily accessible for clearing should it become choked. And in addition to these there is, of course, the independent donkey, and circulating pump suctions. As regards hand pumps, one is fitted in each side gutter; but in the case of small end holds, where there is a well, one at the centre may suffice.

Art. 421. At the after end of the shaft tunnel a well is usually provided in which the water used to cool the bearings and leakage water from the propeller tube may collect before it is pumped out (see Fig. 12, Plate 29, and Plates 109 and 110). Immediately before the **tunnel well**, between it and the end of the double bottom, there is very commonly a bilge space, open to, and forming a well for, the after hold (Fig. 12, Plate 29). As these two wells adjoin one another, the fitting of two long suction pipes to the valve chest in the engine room is usually avoided by placing a **three-way or open-bottom cock**, or small valve chest, at the after end of the tunnel, connecting it by a single pipe to the valve chest in the engine room, and fitting a short branch suction down into each well (Fig. 12, Plate 29). If a valve chest is adopted, then, if the tunnel filled with water when the valves to both wells happened to be open, the water would flow into, and fill the after hold; with a three-way or open-bottom cock this may be avoided, for it may be so designed as not to permit of a communication between the suction pipes to the two wells. With a valve chest the same result may be accomplished by making the **valves of non-return type**, or by gearing them to the upper deck (Art. 424.). If the after peak is a ballast tank, its suction pipe may also be fitted as a branch to the aforesaid valve chest, but then non-return valves to the hold and tunnel well are imperative. When the after peak is *not* a ballast tank, the necessity of fitting a hand pump or steam suction for clearing away its bilge water is avoided by fitting a cock at the lower part of the bulkhead, by which water may be drained from it into the tunnel well; as the cock is in the tunnel, it is always accessible.

In the case of the **fore peak**, if it is not a ballast tank, a small, deck hand pump only need be fitted: a steam suction is unnecessary, for the space within the peak is small, and even if water did accumulate it would do little or no harm, and, moreover, a steam suction is objectionable in that, as it pierces the collision bulkhead, it prejudices, somewhat, its integrity. At one time a sluice valve was fitted on this bulkhead, which served the same purpose as a cock on the bulkhead of the after peak (Art. 430).

Art. 422. The **fore-and-aft position** of the ends of the **bilge suctions** in the various holds depends on circumstances. If the vessel were always on even keel it would not matter to what point they were led, but as there is usually a trim by the stern, they are evidently best placed when at the after end of each hold, which position, as regards the forward holds, is also advantageous in that it minimizes the length of piping. When the supplementary hand pumps are placed at the opposite end to the steam suctions, then all bilge water may be cleared from the hold, however the

vessel may trim. In small vessels in which the machinery is aft, and which have only one long cargo hold (Fig. 1, Plate 20), the bilge water in the latter space has so wide a fore and-aft range, that even a small quantity, if it flowed forward, might, by causing a trim by the bow, remain out of range of the suctions at the after end; in such cases, therefore, an additional suction should be placed at, or near, the forward end of the hold.

Art. 423. The end of each suction pipe is surrounded by a **rose box, strum, or strainer.** This is a galvanized iron box (usually of cast iron) 9 or 12 inches square, having all its sides perforated with small holes (Fig. 13, Plate 73). Its purpose, of course, is to strain the dirty bilge water, so that solid matter may not pass into and choke the suction pipe or the valves of the pump. Lloyd's rules require the area of the perforations to be twice that of the suction pipe, so that, though partially choked, it may still pass sufficient water. It should have a hinged lid or sliding sides, to give access to its interior. The suction pipe passes loosely into the box, with its end about 1 inch above the cement. The box should be fixed so that it may not move with the rolling of the ship, and wear away the cement and pipe.

As an additional security against choking of the pumps, a perforated partition, or strainer, is sometimes fitted across each valve chest (as shown in Fig. 11, Plate 74), between the pump suction pipe and those leading to the holds; and an air-tight lid is provided, upon opening which the strainer may be cleared. The suction pipes for pumping out the ballast tanks need not be provided with rose boxes, for no dirt of a kind likely to cause choking finds access to the tanks, the flooding valve on the vessel's side, through which they are filled, being covered with a strainer. Very commonly their lower ends are expanded, trumpet-fashion, for then they may be placed closer to the cement, the large periphery offering ample passage for the water; the formation, moreover, conduces to an easy flow of water into the pipe. Special cast-iron ends are often employed, having studs or teeth projecting downwards from the lip to ensure a sufficient clearance from the cement (see A, Fig. 31, Plate 73).

Art. 424. The arrangement of the **suctions in the ballast tanks** of a double bottom is much the same as that just described for the bilge suctions. In a large flat-bottomed tank, a centre-line and side or wing suctions are fitted. The latter are for emptying the tank when the vessel has a list, for as the water sinks in the tank during the pumping, it may flow to one side and heel the ship; as they are regarded as auxiliary, they are usually of smaller diameter than the centre-line suction. If there is a good rise of floor, as in the end tanks, wing suctions are dispensed with. In tanks which are divided by a fore-and aft central division, one suction is fitted in each half. Ballast suctions vary greatly in diameter; from 2 inches in small vessels to 4 inches in large ones is perhaps the ordinary practice; but in large vessels, where rapidity in filling and emptying the tanks is desired, they may be 6 inches in diameter. As ordinarily arranged, two or more valve chests are provided for the forward and for the after tanks, which permits of one set of tanks being filled while another is being emptied.

In small vessels the tanks are emptied by the donkey pump. Large vessels have a special ballast pump, the donkey, of course, being also available. **Ballast pumps** vary greatly in power; when of ordinary capacity they may pass 60 tons of water per hour, but some may deal with as much as 300 tons. Three types of pumps are available for this work: the ordinary *double-acting piston pump*, the *centrifugal*, and the *pulsometer*; the latter has the advantage of being noiseless in action.

Ballast tanks are filled through their suction pipes. For this

purpose a flooding pipe is led from the valve chest to a sea cock on the vessel's bilge in the engine room; when the cock is opened the chest fills with sea water, so that any tank may then be filled by simply opening its particular valves in the chest. In high-class vessels separate chests are provided for the bilge and ballast suctions, in ordinary cargo vessels the same chests are very commonly made to serve both purposes; in which case, to prevent sea water from flowing into the holds, the bilge suction valves must be of non-return type. The sea cocks in the engine room are fixed well up on the vessel's bilge, for if placed below the bilge they might be submerged in bilge water and inaccessible, and, when filling the tanks in harbour, quantities of mud might enter. The bilge, moreover, is an advantageous position in that the valve—of brittle cast-iron—is not exposed to local pressures from contact with quay walls or a stony bottom.

A deep ballast tank which extends above the light waterline cannot be filled by gravity, *i.e.* through an open valve; it must be pumped up. This is done simply by reversing the flow through the ballast pump, causing it to draw from the sea and discharge into the tank. And even though the top of a deep tank may be below the light water-line, provision is usually made for filling it through the pumps, for if filled by gravity, the rate of filling, as the water rose in the tank near to the sea level, would be slow. Peak tanks and others in which fresh water is carried are filled from the deck by a hose, through the sounding or air pipes (Fig. 19, Plate 75). If the double-bottom tanks are filled when the vessel is floating light, in the usual way, by opening a valve, the speed of inflow of the water is slow, and more particularly when it has to pass through valve chests and long lengths of piping: a long 5-inch pipe, for instance, lying 15 feet below the surface, would pass little more than 200 tons per hour. In large vessels, therefore, whose double-bottom tanks may be very capacious (in a vessel 500 feet long they may contain 1800 tons), and where it is desired to fill them quickly, it is usual so to arrange the ballast pump that it may discharge into them from the sea, for water may be forced by a powerful pump through long and circuitous piping much faster than it would flow through them if impelled only by the force of gravity.

Art. 425. In the **machinery space** there are numerous **under-water valves** on the ship's side, and it is very important that these, the pipes leading from them, and the inner distributing valves, should be so arranged that sea water may not flow into the ship as a result of carelessness or inadvertence on the part of the engine-room staff. At one time this danger was not always provided against, and accidents sometimes occurred involving the loss of the ship.[1] All valves, or their controlling spindles, should be placed well above the lower platforms, so that, should water rise in the machinery space, they may not at once become submerged and inaccessible. And, for a similar reason, the donkey pump—and boiler—should be placed as high as practicable (Art. 230).

There are several ways in which water might flow into a ship by the sea cocks in the machinery space. Should a valve chest, for instance, have the double duty of serving for both the bilge and ballast suctions, which is a common arrangement in ordinary cargo vessels, there is a chance, when it is opened to the sea for filling the tanks, of some of the bilge suction valves being open, in which case the water would pass into the holds. This danger is avoided if separate valve chests are provided for the holds and for the tanks; or, in cases where it is found expedient to use one, by making the valves of non-return type. A **non-return valve** is shown in

[1] See Mr. Martell's paper in the *Trans. Institution of Naval Architects*, 1880, and Mr. Morley's paper of 1876.

Fig. 12, Plate 74; it is simply a screw-down valve, the spindle of which has no connection with the valve, so that while it may press it down on its seat, it is incapable of lifting it; water, therefore, can lift the valve and pass upwards, but cannot return and flow into the hold. When employed for bilge suctions these valves are not entirely reliable, for should chips and dirt from the bilge water get between a valve and its seat, it would not close. It is evidently very desirable, therefore, that separate valve chests should be provided for the two distinct duties of flooding the tanks and pumping the bilges.

Sometimes **non-return valves** are so designed that they may be lifted if required, and thus pass water either way. The only difference from an ordinary non-return valve is that the spindle, when screwed up beyond a certain point, takes contact with a vertical extension of the valve and lifts it. They are largely employed in warships for the suction pipes to compartments which, on exceptional occasions, may require to be flooded with water; the magazines, for instance, in case of fire, or wing compartments, to bring the vessel upright should she take a list. They are also suitable for the suction and filling pipes of deep ballast tanks which may also carry cargo, so that a small opening movement of the valve spindle, inadvertently made, may not admit water; but here the more thorough precaution should be taken of locking the valves with chain and padlock when cargo is carried in the tank, or of disconnecting the pipes and fitting blank flanges on their ends, supplementary suction pipes being provided for pumping the bilge water from the tank when used for cargo. The non-return valve shown in Fig. 23, Plate 73, is fitted to the lower ends of Downton suction pipes, and sometimes to those of ordinary hand-pump suctions, to ensure regular lifting action, when, owing to the vertical movement of the ship, the water might dance up and down in the pipe, and also so that the pipe above may always be charged with water and ready for work. In warships they are largely employed, as a precaution against water passing down damaged suction pipes, into the holds below the watertight protective deck.

The fact that the bulkheads are pierced by suction pipes may often greatly prejudice their reliability as watertight partitions. Thus, in the event of a hold (or peak compartment if provided with a steam suction) being filled with water as a result of collision or grounding, the water would at once flow along its pump suction pipes to the valve chest in the machinery space; and if the valves of any of the other suction pipes in this chest happened to be open, or improperly closed, perhaps because of an obstruction on their seats, the water would flow through them into the other holds. This danger it is usually sought to avoid by making all bilge suction valves of non-return type. In warships they always are of this type, and where large suction pipes pierce important bulkheads, they are provided with valves controllable from the upper deck, so that, when shut, the integrity of the bulkhead is assured.

Art. 426. Bilge suction pipes are usually **led fore-and-aft** over the tank side gutters (Plate 105), or they may be placed within the double bottom; those to the after holds are usually led along the tunnel, whence they pass out, over the tank top, or within the tank, to the side gutters. Sometimes one or two pipes may be led along in the tank side gutters, passing through the lightening holes in the bracket plates; they are then out of the way and well protected, but if they should become choked or defective, they are not very accessible nor easily removed for repairs.

Ballast-tank suctions are usually **led along within the double bottom** (Fig. 31, Plate 73), for they are then out of the way of cargo and well protected, and they do not require to pierce the tank-top plating. They

pass through the lightening holes in the floors, to the edges of which they are fixed by iron clips (Plate 105). They must be firmly secured, for, if they shook and vibrated, the friction with the plate edges would cause rapid wear, and if the pipe got adrift it might break or become loose in its joints, leak, and perhaps pass water into some other compartment. In large vessels, having numerous, large, ballast suctions, they are sometimes led along the top of the tank, each one passing down as required (B, Fig. 31).

Bilge suction pipes may be **of lead or iron,** malleable or cast. Although a lead pipe is dearer than an iron one, it is advantageous in that it can be expeditiously fitted, in long lengths, and it may be passed through holes and round corners without jointing. If not well boxed in it may become battered, but if so badly as to require renewal, the lead has still its market value. To be strong enough, a large lead pipe must be thick,[1] say ¼ inch in the case of a 3-inch pipe (they are often thinner); when so large, therefore, it is usually found expedient, on the score of economy, to employ cast-iron pipes, using lead for the bends, where they turn down into the bilge or pass round corners at bulkheads, etc. If an iron pipe is fitted in a straight length between two bulkheads, it is apt to strain at its joints, or fracture, through longitudinal expansion and contraction; this is avoided by making a short portion of the pipe, where it passes through the bulkeads, of lead, and giving it a bend ("expansion bend," see Fig. 31, Plate 73). This is also advantageous in that it is not then necessary to make the iron pipes of any precise length. All bends in the bilge suction pipes should have an easy curvature, for sharp elbows induce choking; if a sharp bend is unavoidable, a *clearing plug* should be provided (as shown in Fig. 7.) All bilge suction pipes are liable to choke, through grain and refuse accumulating and perhaps swelling therein; when a lead pipe is battered—as it often is—it is particularly liable to choke. They are sometimes cleared by pumping water forcibly through them, back into the bilge; and sometimes provision is made for blowing through steam, which may be a useful arrangement in case of fire, in that it enables the holds to be filled with steam, so that the fire may die out for lack of air.

When bilge suction pipes pass through a ballast tank (as they must do when there is a 'midship deep tank), they are subjected, when the tank is open to the sea, to the full pressure of sea water; this part of the pipe should, therefore, be particularly strong, well fitted and protected. It should not be of lead, for if battered or defective (not an uncommon condition in a lead pipe) it might fail under pressure, and form a conduit for the passage of the sea water from the tank into the hold. A defect in the same pipe, in a cargo hold, although very undesirable, would be comparatively unimportant.

To facilitate the repair of choked or defective **piping**, the **joints** should be conveniently arranged for taking the different lengths asunder. A lead pipe is usually jointed by a soldered or *wiped joint* (Fig. 17, Plate 73), but it is well that a few *flanged joints* should be introduced (Fig. 18). The usual connection of a lead pipe, where it passes through a bulkhead, is shown in Fig. 28; the iron washer is introduced to distribute the binding pressure of the bolts over the soft lead flange. Another method is shown in Fig. 27. Cast-iron bilge suction pipes are supplied in comparatively short lengths, and are connected by flanged joints, which are made air-tight with putty and felt, or, if the flanges are not machined, with rubber washers (Fig. 26). Wrought-iron pipes are usually supplied

[1] Lead pipes are not ordered by thickness, but by weight; substantial piping of 1½-inch, 3-inch, and 4½-inch bore should weigh respectively about 14, 38, and 65 pounds per yard, but, of course, much depends on the purpose of the pipe.

in 15-feet and 20-feet lengths, and, to avoid corrosion, they are galvanized. They are connected either by flanges (Fig. 20), or by *thimble* or *sleeve joints* (Fig. 19). A thimble joint is easily made, but as it is tightly jammed, and cannot readily be taken adrift, it is unsuitable for bilge suction pipes. In warships all pipes, small or large, are of wrought iron (excepting the fire-main, which is of copper), to the exclusion of lead or cast iron; where they pass round corners they are heated and carefully bent.

Ballast suction pipes over 2 inches diameter are usually of **cast iron**; if over, say, 4 inches, they are often of galvanized **wrought iron.** Wrought iron is superior in that it is lighter and, not being brittle, is less liable to fracture by straining or shocks such as might occur if the pipe got adrift or if the vessel bumped on the ground. When situated in a tank, the fracture of a ballast suction pipe would not be a serious matter; but if outside, in a cargo hold, it would, for in filling the tank the hold also would fill. The joints of cast-iron pipes are usually flanged (Fig. 26, Plate 73); when within the double bottom, however, they are often of spigot-and-faucet type (Figs. 24 and 25), and, instead of making them tight with the usual lead grouting (which, owing to its rigidity, might not be permanently tight), an india rubber packing ring is usually fitted over the spigot. With good rubber this is an excellent joint, for it is easily made, and, being flexible, avoids the necessity for expansion bends; when subjected to water pressure, however, it is not a secure joint, and it can, therefore, only be employed for ballast suctions *within* a double-bottom tank.

Art. 427. In order that the ballast tanks may be filled quite full, provision must be made for the escape of the contained air, otherwise, of course, the water would not rise. For this purpose **air pipes** are led from the tank top, usually to the upper deck, where, should water overflow, it would do no harm (Figs. 12 and 14, Plate 73). An air pipe should, of course, be placed at the highest point of the tank top. In a large tank, with a flat top, there should be one at each corner; in many cases there are only two, which may be placed both at the forward end, or one at each end, the one to port and the other to starboard; but this, of course, is not sufficient to ensure the complete filling of the tank, for if the vessel should have a list and trim by the bow or stern, an air cushion may form at either of the other corners. As air can escape through a pipe more readily than water, a single air pipe might be smaller than a single filling pipe. In filling a tank, however, the water, when it is nearly full, is apt to blow up the air pipes and choke them as regards the passage of air; consequently, large air pipes are desirable. The sizes adopted in practice vary considerably; from $1\frac{1}{2}$ to 2 inches is common, but in large vessels they may be 3 or even 4 inches diameter. In tanks which may be pumped up, the air pipes should be as large as the filling pipe, for immediately such a tank becomes full the pump may force the water up the air pipes, and if these are small, the resistance offered may cause a considerable bursting pressure in the tank. It is also very important, in such cases, that the air pipes should be permanently open; if closed on the upper deck with screwed plugs, the omission to open them when the tank is being pumped up might have serious results; cases have occurred where a tank top has actually burst under the excessive hydrostatic pressure of the pumps. And, similarly, in emptying the tank, if the air pipes were closed, a vacuum would be formed within the tank, tending to collapse the top—a serious matter in the case of a deep tank, whose top is supported by long flexible beams.

As regards the arrangement of the air pipes, the best practice is to carry them up the vessel's side and through the gutter waterway of the upper deck, and fit over them goose or swan necks (A, Fig. 12, Plate 73); or

merely bend the pipe round as shown at B, Fig. 12, for then it is permanently open, and cannot, unless completely submerged, pass water into the tanks. Otherwise, they may terminate with a screwed plug or hinged flap cover, which, being flush, permits of their being carried up to any part of the deck. The hinged cover is superior to the plug in that it can open under pressure, but, of course, it is no better when (as the tank is being pumped out) air seeks to pass down; further, it cannot be lost like a plug, for this often happens, in which case, if the pipe is left open at sea when the deck is flooded with water, water may pass down the pipe, so that if the tank is already full, it may be subjected to a permanent and objectionable hydrostatic pressure. In vessels which carry deck loads, flush covers are objectionable, in that they may be covered up with cargo and inaccessible. When fresh water is carried in the double bottom, as is usual in passenger and cattle steamers, it is, of course, essential that no sea water shall gain access; in such cases, therefore, automatic float valves are sometimes fitted at the ends of the air pipes, which, while permanently open for the passage of air, will close should water seek to enter. One of these valves is shown in Fig. 13, Plate 74; the ball of light material, cork or rubber, lies normally in the position shown by the dotted lines; should it be immersed in water, it floats up and blocks the passage. They may be fitted in connection with an ordinary swan neck (Fig. 19, Plate 75), or, to avoid encumbering the deck, they may be fitted on the vessel's topside plating (as shown in Fig. 13, Plate 74), or in connection with one of Utley's patent ventilating sidelights (Art. 453).

Art. 428. Sounding tubes or pipes are fitted to all cargo holds, peaks and ballast tanks (Fig. 31, Plate 73), for the purpose of ascertaining the depth of water in the compartments. One at the after end of each hold is sufficient, but where there is a double bottom and no well, two are required, one in each side gutter. Soundings are taken at sea periodically, by passing a rod, 3 or 4 feet long, with cord attached, down the pipe, and on its withdrawal noting how much of it has become wet. The pipe usually extends to the upper deck, where it terminates with a screwed plug; if the upper deck is not sheltered from the weather, it is preferable, where cargo is not carried in the 'tween decks, to stop it at the second deck, for when deck water is washing about it is a difficult matter to keep the rod dry when sounding. When on the exposed upper deck, it is well to raise the end of the pipe a few inches above the deck, so that the deck drainage water may not pass down the pipe and wet the rod. When a tank air pipe is at the centre line, it may also serve as a tank-sounding pipe, and sometimes sluice-valve rods are arranged for this purpose (Art. 430). Every time that soundings are taken the rod strikes the same patch of cement on the vessel's bottom, so that in course of time it may break it away. Cases are on record where the continued bumping of the sounding rod (aided by corrosion) has actually worn a hole through the shell plating. To prevent this a small iron plate should be embedded in the cement just below the pipe (Fig. 31). Sometimes a plug is screwed into the end of the tube, and slots cut immediately above it, to admit the water (Fig. 15).

In order that the engineer, whose duty it is to fill and empty the tanks, may know when they are full without going on deck to take soundings, the sounding pipes of the tanks abaft the boiler room bulkhead sometimes terminate (with a screwed plug) within the machinery space or tunnel. And in high-class vessels it is common to lead a small **tell-tale pipe** (about 1 inch in diameter) from each tank to the machinery space, each pipe terminating with a cock just above the platforms, so that, when opened, an outflow of water may announce when the tank is full.

Care should be observed to make the union of the **sounding and air pipes** with their brass **deck-plates** quite watertight, so that water passing up or down the pipe may not enter the hold; valuable cargo has sometimes been damaged through the careless fitting of these parts. The designation of each pipe should be engraved on its deck-plate; sometimes this is not done, in which case those on board may not be sure of the precise purpose of the pipe. The air and sounding pipes should be of galvanized iron. Those to the tanks should be of substantial material and be well jointed, for they are subject to water pressure, and, in reality, form part of the tank. Sometimes they are made of brittle material, little better than gas piping, with flimsy joints, in which case they may fracture, leak, and damage cargo. All such pipes should be boxed in with substantial wood or iron casings, so that they may not be injured by cargo.

Art. 429. To pump the bilges or tanks quite dry is seldom practicable, for the end of the pump suction is at least 1 inch above the cement; and even if the latter were thick enough to permit of its being excavated for the end of the pipe, the flow of water when only 2 or 3 inches deep, through the limber and drain holes, is slower than the lifting power of the pump. The necessity for removing all water only arises when it is required to clean the bilges, inspect the cement, or examine the tanks, and as this is usually done in dry dock, the simple plan is adopted of fitting screwed plugs (1 inch or $1\frac{1}{2}$ inches diameter) in the garboard strake, one at the after end of each tank, hold, or pump well, upon removing which all water at once flows out. These **drain-hole plugs** are usually of brass, for when of iron the thread is found to corrode; when a brass plug is well greased, and coated on the outside with paint, the contiguous iron is not found to suffer from galvanic effects (Art. 458). There is a chance, if the vessel should scrape the ground, of their being torn out; this would be a serious matter if it occurred to a plug in one of the holds, but the danger may be avoided by fitting a small doubling plate on the shell, so as to give the plug an ample grip in the plating.

Art. 430. Formerly it was a universal custom to fit a sluice valve at the bottom of each bulkhead, controllable from the upper deck (Figs. 9, 10, and 11, Plate 73). The primary purpose of a **bulkhead sluice** is to allow the water, which, in the event of a leak, might enter a hold, to flow into the adjacent one, so that a leak too large for the pump suctions of the one hold to cope with, might be kept under by the simultaneous action of those in the adjacent ones. Under certain circumstances this might be very advantageous, but in practice there are various matters which more than discount any probable benefit. In the first place, it would be a rare chance that a serious leak, due, say, to collision or grounding, would be of just such a magnitude as to be too great for the pump suctions of one hold, but within the power of those of two or three, for a vessel's pumping power, taken all together, is small compared with the inflow that might result from even a small opening in the shell. Further, should the leak be in the foremost or aftermost hold, the inflowing water, if not at once got under, might so trim the vessel that it would not flow as required, towards 'midships. They are very objectionable, in that they prejudice the integrity of the bulkheads as watertight partitions. A bulkhead may save a ship from foundering, but should its sluice valve be open, through carelessness or inability to close it at the crucial moment, the bulkhead becomes practically non-existent. In many cases those in charge of the ship are forgetful or unaware of the existence of the sluice valves in the bulkheads. Very commonly those in the forward bulkheads are kept permanently open, for as all bilge water then finds its way to the machinery space, it may be

removed by the steam bilge pumps, kept constantly at work in this space. If, in an emergency, it should be required to close them quickly, the deck-plates through which they are worked may be covered by deck cargo, or the key may be lost, or the valves may be inoperative, or jammed, or it may not be known which is the closing and which the opening movement. As the valves are placed in the vessel's bilge, below the ceiling planking, they receive little attention; they may, therefore, become clogged with dirt, so that they cannot be closed, or the gearing and the sluice itself may be disordered by corrosion and wear and tear.

For the above reasons bulkhead sluice valves are now rarely fitted; each hold is provided with hand and steam pumping power more than sufficient to cope with ordinary leakage, so that in the event of a serious inflow of water, imperilling the ship, the bulkheads are reliable as water-tight partitions. In warships there are numerous sluice and other communicating valves, but here the prevailing conditions are different from those in merchant vessels, for no dirt is allowed to collect in the bilges, the valves are always accessible, they are constantly worked, and the mechanism is of the most perfect kind. Lloyd's rules permit of bulkhead sluice valves on condition that they are always accessible, excepting, however, the important collision bulkhead, in which, to ensure reliability, no valve whatever is allowed. In a vessel whose holds are full of cargo, the only bulkheads whose lower parts are always accessible are those of the machinery space and the after-peak bulkhead, and in these, sluice valves might, in an emergency, be exceedingly useful; for, with the circulating pump in action, the pumping power of the machinery bilges is very great, and it would evidently be advantageous if this great power were also available for clearing, on occasion, the two adjacent cargo holds. When fitted on the engine-room side of the bulkheads they may be kept in good order, for they may be examined and overhauled, if required, during a voyage. When there is a double bottom, bulkhead sluices, if fitted, are placed one in each side gutter; if there is no double bottom, one central one suffices.

Sluice valves must be geared to the upper deck, or to the second deck if it be well above the load line, so that they may be controlled, however deep the water in the bilged compartment. They are worked by a screwed spindle, which may engage with a nut, in one with the door of the sluice (Figs. 10 and 11, Plate 73), or through a fixed nut above (Fig. 9). The latter plan is advantageous in that, as the rod itself moves up and down with the sluice, its position in the deck plate indicates that of the sluice. When the deck plate forms the fixed nut (Fig. 9), the rod, when the sluice is forced down, suffers a compressive thrust throughout its length, so that it must be strong or well guided. When the sluice door forms the nut, the rod has no vertical movement in the deck plate, so that the position of the valve, whether open or shut, is uncertain. If, in such cases, the closing movement is indicated on the deck plate by an arrow, the valve may be jammed down tight, but even then whether or not it is shut may be doubtful, for it may be obstructed by chips or dirt; but a simple means of knowing is to mark on the deck plate the number of revolutions necessary to close the valve from its full open position.

In warships the sluice valves and watertight doors are provided with **deck plates** having special **indicating mechanism**, which shows the position of the door or valve, and these are also adopted in high-class merchant vessels. Sluice valves are usually of brass or gunmetal; when immersed in salt bilge water they may, therefore, cause, by galvanic action, rapid corrosion of the contiguous iron; to avoid this, felt or hardwood packing should be placed between the bulkhead and the valve, and the lower

part of the controlling rod should be of gunmetal. When a straight vertical lead from the valve to the deck is not practicable, levers are usually introduced (see A, Fig. 9, Plate 73). In warships direct leads are seldom practicable, and, instead of levers, carefully fitted bevel gearing or universal joints are employed; all wheels are of gunmetal, and, for the sake of lightness and strength, the controlling spindles are of steel tubing.

Very commonly, instead of fitting sluice valves on the bulkheads, large **cocks**, about 2 inches diameter, are employed. Sluice valves are advantageous in that they offer a large passage for water, and in closing them they may, by their guillotine-like action, cut through obstructions, but, on the other hand, as dirt is apt to gather on their large exposed sliding surfaces, it may not always be possible to close them entirely. Cocks are advantageous in that one-quarter of a turn of the rod is sufficient to close them; with a sluice, six or seven complete turns are required; and, further, the condition of a cock, whether open or shut, may be indicated by a line across the top of the spindle. Sometimes the spindle is a tube, so that it may be used for sounding, the passage of the rod through the cock serving to force out obstructions.

Art. 431. Hand **deck-pumps** have usually a straight lead to the bilge, and are placed close to a bulkhead, where their tail pipe may be conveniently cased in. They are worked by a hand lever, pivoted to a portable standard, which ships into a socket in the deck (Fig. 8, Plate 63). Sometimes they are arranged to be worked by an adjacent steam winch, by means of a long connecting rod, the hand lever giving place to a stout bell crank. The *chamber* in which the bucket of the pump works may be of cast iron or copper; if the former, it should be lined with brass, for iron corrodes, and, becoming rough, greatly reduces the efficiency of the pump. The *tail pipe* leading from the chamber to the bilge is usually of lead, and is half the diameter of the chamber. Hand pumps vary in size (*i.e.* the diameter of the chamber) from 4 inches in a small vessel or hold to 6 inches in a large; if larger than this they cannot be conveniently worked by a hand lever. In a first-class pump the bucket has a *cup leather* and well-fitted lift valve; the lower, or *foot valve*, is usually of *plug* type (see Fig. 8). They discharge by overflowing on deck, but in high-class passenger vessels, to avoid soiling the deck with dirty bilge water, an overflow pipe is led across under the deck, through the ship's side or into an adjacent scupper pipe. A theoretically perfect pump can lift water from a depth of about 34 feet (the height of the water barometer), but in practice the imperfection of its vacuum limits its lifting power to about 24 feet. The bottom of the chamber should, therefore, not be more than this height above the rose box. In large vessels, whose depth may exceed 24 feet, an extension-piece of cast iron is fitted above the chamber proper, so that the latter may be within 24 feet of the rose box.

Art. 432. As **sailing-ships** have no steam pumping power, they are provided with **specially powerful hand pumps.** These vary in size from 5 to 7 inches, and they are always in duplicate, *i.e.* there are two chambers and two tail pipes, worked simultaneously by the same mechanism, which consists of a horizontal crank shaft, fly wheel, and winch handles, mounted as a fixture on the pin rail around the main mast. They are usually ordinary lift pumps, but in some cases they are of the more powerful double-acting type, in which the pistons have no valves, and lift water on both the up and down stroke. The tail pipes are of cast iron, and as they are large and have a straight lead to the bilge, they are not liable to choke, and rose boxes are not essential. To permit of the pump well being examined and cleared, the wood casing surrounding the pipe is made large

enough for a man to pass down, access to the casing being obtained through a manhole or ventilator in the upper deck. The fresh-water tanks are usually placed immediately abaft the pumps, so that they are accessible by the same means. In ships which have a flat bottom an additional wing suction is sometimes led out to each bilge, so that, when heeled over at sea, all bilge water may be removed; they may be worked by independent hand lever pumps, or in conjunction with the main centre-line pumps. In the former case the suction in the starboard bilge should have its chamber on the port side of the deck (and *vice versâ*), so that in heavy weather the men working the pump may have the protection of the weather bulwark.

Hand pumps are rarely used, for in steamers the steam pumps do all the necessary work, and sailing-ships are usually perfectly tight. As they are, therefore, liable to get out of order and be useless in an emergency, they should be overhauled periodically and made to lift water, for although the pump gear may be all right, the suction pipe may be choked or leaky; lead pipes, for instance, are sometimes gnawed through by rats.

Art. 433. A **Downton pump** is a hand force-pump[1] of special type (Fig. 4, Plate 73). The pump chamber is contained in a pedestal, the upper part of which forms an air chamber (for continuous discharge) and contains two cranks, by means of which two pistons are made to reciprocate and give the effect of two double-acting pumps, *i.e.* in such a way that each revolution of the pump handle may lift four times as much water as one up-and-down stroke of an ordinary bucket pump of the same size. As so much work is performed in each revolution it is hard to drive, but long crank handles may be provided so that any number of men may work together. If required, it may be placed on a lower deck and worked from the upper, by means of a vertical shaft and bevel-wheel gearing. Besides being very powerful, it has the peculiar advantage of being able to pump from any one of a number of compartments, or from the sea, and of discharging wherever required. This is accomplished by leading the suction pipes from the various holds (and one from an under-water sea cock on the vessel's side) up to a *deck plate* or *suction plate*, conveniently placed near the pump, where each one is covered with a screwed cap (Fig. 4). From the centre of the deck plate a short tail pipe is led to the Downton, and when it is required to pump from any particular compartment, all that is necessary is to connect the end of this tail pipe with the end of the suction leading to that compartment, this being done by means of an adjustable *goose-neck* (see Fig. 4). The discharge pipe (or "rising-main," as it is termed) is led overboard, but it may also connect to the fore-and-aft *fire-main*. When pumping from the bilge, the water is, of course, discharged overboard. When sea water is required for washing decks, extinguishing fire, or filling the *sanitary tank*, the goose-neck is coupled with the suction from the sea valve, and the discharge diverted into the fire-main, through which it may be impelled wherever required.

In steamers, a **Downton pump** is now very commonly **substituted for the numerous deck hand pumps**. It is usually placed in a recess in the side of the engine-room casing, at the level of the second or third deck. Its tail pipe is connected to the ordinary steam-pump valve chests, situated in the engine room and stokehold, so that the steam suction pipes to the various holds also serve for hand-pumping operations. The advantage of a Downton over numerous hand pumps is that it may be

[1] A *force* pump differs from a *lift* pump in that the upper part of the chamber is closed, so that the bucket or piston not only lifts the water, but forces it out, discharging it through piping wherever required.

placed in a sheltered position; deck hand pumps may not be approachable in heavy weather, but, of course, so long as the vessel has steam pumping power there is no need to use the hand pumps. It is also advantageous in that it is a more powerful and efficient mechanism; the fitting of it is simple and economical compared with the fitting of numerous deck hand pumps, and whereas the latter, with their numerous portable parts, may, owing to disuse, often get out of repair, a Downton, being self-contained, is not so likely to get out of order. On the other hand, a Downton pump which has numerous valve-chest connections is more likely to choke when in use; and, moreover, the necessity for a man to go below (to the bottom of the engine room or stokehold) to open and shut certain valves in order to obtain a connection to the particular hold requiring pumping, is a serious disadvantage, for in the event of water rising in the engine room (perhaps in harbour, when only hand pumping power is available) the valves might not be approachable. This objection can be met, of course, by the use of a deck suction plate or deck valve chest, as already described. Downton pumps are often fitted in passenger vessels for the purpose of distributing salt water when steam power is not available; and when a suction is led from its deck plate to the fresh-water tanks, fresh water may be distributed to the various cisterns throughout the ship. In warships high-class Downton pumps are extensively employed, for here unlimited manual labour is available for working them; they are well adapted for pumping the numerous small watertight compartments, and, when suitably placed, at various fore-and-aft points, they dispense with long suction pipes and avoid the piercing of numerous holes in the watertight bulkheads.

Art. 434. In all vessels **provision** is made **for extinguishing fire.** In small steamers the donkey pump serves as a fire-engine, a discharge pipe being led to the upper deck, to the end of which a hose may be attached. Large passenger steamers have an independent steam **fire-engine pump**, which, of course, may also be used for washing decks, the requirements for this service being identical with those for extinguishing fire. The fire-engine discharges into the **fire-main.** This is a galvanized iron pipe, from 2 to 4 inches diameter, led fore and aft along by the gutter or bulwark, or wherever is most convenient, having nozzles at intervals of about 50 feet, so that at every part of the ship a length of hose may be quickly attached; and in passenger vessels branches are led from it, up or down, to serve the various 'tween-deck spaces, and across the deck where the central part is blocked with deck houses or casings. As just noticed, if a Downton is carried, it also may discharge into the fire-main. In large sailing-ships a Downton or rocking-lever force pump is carried for this purpose, the fire-main being led along under the main rail; in others the only provision for extinguishing fire is a small portable force pump, having a wire-bound hose for its sea suction; and steamers also are sometimes provided with this appliance as a supplementary means of extinguishing fire.

Art. 435. In large passenger vessels, a constant **supply of sea water,** by gravitation, is required **for the baths and water-closets.** For this purpose a large cistern, the "*sanitary tank*," is placed on the top of the machinery casing, and is kept full of sea water by a small pump, the "*sanitary pump*," worked by the main engine. As the pump is always at work, there is a constant overflow from the tank, which, instead of being passed overboard, is conveyed into the water-closet soil pipes, and emigrants' and crews' troughs, to flush them continuously. The water is distributed from the cistern by a fore-and-aft, galvanized iron main (led along under the beams, or wherever is most convenient), having branches with cocks to

the various places. To supply **hot sea water** for the baths, a cistern is provided in which there is placed a steam-heater, formed of a coil of steam piping in connection with the boilers; it is filled from the sanitary tank, the supply being regulated by an automatic float-valve. When the main engine is not working, the sanitary tank may be filled by the donkey pump or Downton.

In **sailing-ships** the **supply of sea water** is obtained through an underwater sea cock in the fore peak. A suction pipe being led from this to a small force pump (termed the "*head pump*") or Downton, placed at the end of the forecastle, which is arranged to discharge into the fire-main, the seamen's water-closet, or into buckets for conveyance to the water-closet cisterns in the poop. A sea cock is a source of danger, for it may become deranged, the bolts fastening it to the shell plating may give way, or the suction pipe may leak; for this reason, in sailing-ships, it is always placed in the peak, where it is accessible and where water, should it enter, would do little harm. The cock is usually permanently open. It should be controlled by a spindle from the upper deck, for when the peak is full of coal, as is usual, it may not always be accessible; usually, however, a wood trunkway is provided down which a man may pass to the cock. The cock is of brass or gunmetal, and the bolts connecting it to the shell are usually of iron; but as these, owing to galvanic action, are particularly liable to corrosion (in some cases they are found wasted away to mere wires), they should be of Naval brass.

Art. 436. In passenger vessels there must be a **constant supply of fresh water**, by gravitation. To provide this a large cistern (the *daily-supply tank*) is placed, like the sanitary tank, on the top of the machinery casing. It is filled periodically from the fresh-water tanks in the hold, by a Downton or by a small steam pump in the engine room specially furnished for this work, and provided, it may be, with a water meter to indicate during the voyage how much fresh water is being consumed. The fresh water is conducted from the cistern to the various lavatories, pantries, and galleys (and sometimes to the cisterns over the wash basins in the passengers' cabins) by a fore-and-aft main and branches. A tank, having a steam-heating coil, is also provided for supplying **hot fresh water** to the pantries and galleys. In sailing-ships and small cargo steamers the fresh water is obtained from the tanks in the holds by a small lift-pump, portable or fixed.

Large **ocean-going passenger vessels** may carry immense quantities of fresh water (perhaps 100 tons or more), and **distilling apparatus** is always provided as well, for producing fresh water during the voyage. Some vessels carry comparatively little fresh water, but have, instead, specially powerful distilling apparatus, capable of producing from 20 to 40 tons per day. As a rule, however, the distilling apparatus serves merely as a stand-by, because to distil fresh water by boiling down salt, involves the burning of large quantities of coal. **Fresh-water tanks** may be built complete in themselves, and be placed in any convenient part of the 'tween decks or hold, or they may be in one with the structure of the hull, their containing walls being formed, in whole or in part, by the vessel's bulkheads, decks, or side plating. One or more of the **double-bottom tanks** are very commonly used for fresh water, for feeding the boilers or for passengers or cattle. If employed for drinking water, these particular tanks are appropriated solely for this purpose, for if used occasionally as ordinary ballast tanks they might be filled with the dirty water of a harbour, when, of course, the purity of the fresh water subsequently carried would be very doubtful.

Self-contained tanks are advantageous in that there is no chance of the water being spoiled by salt water leakage. When a large volume of water is required, several tanks are provided, for a tank which held more than, say, 20 tons would be too unwieldy to fit in place, and would have to be strongly constructed, with division plates. When fresh water is distilled, it is passed, while still hot, into one of the fresh-water tanks, where it cools before being used. The position of the fresh-water tanks varies; formerly they were often placed just abaft the collision bulkhead, and in some cases the outer ones, to economize space, were built to the form of the hull, but it is well that a space should be left, so that the vessel's sides may be accessible for cleaning and painting. Ordinary cargo steamers do not carry much fresh water, and in these the tanks are often placed at the after end of the bridge, one or two at the centre or on either side, or they may be placed in the hold, over the thrust recess, in which case the engine-room bulkhead and tunnel top may be made to serve as one of the sides and the bottom. In sailing-ships they are placed abaft the main mast. When placed in the hold they may be very deep, in which case they may suffer considerable water pressure, sometimes the resulting bulging of their sides is quite pronounced. They are filled by hose through a pipe from the upper deck; and in large vessels, where the upper deck is high above the tanks, the filling pipe should not be connected to the tank top, but should be placed over a manhole, for if the tank is of the usual light scantlings, and the water were allowed to rise in the pipe and overflow on the upper deck, the bursting pressure at the lower part of the tank might be more than it could safely bear. The thickness of the plating varies from $\frac{1}{4}$ to $\frac{5}{16}$ inch, and the corner and stiffening angles are usually $2\frac{1}{2}$ by $2\frac{1}{2}$ by $\frac{5}{16}$ inch; in many cases, however, the side plates are flanged. Special cast-steel corner pieces are sometimes employed (see Fig. 15, Plate 55). The sides are strengthened against bursting pressure by fitting cross ties between the stiffeners; and the ends of the latter at the corners should be connected by plate brackets. Each tank is provided with an air and sounding pipe, and with a manhole and drain plug; also, with a suction pipe to a steam pump in the engine room, or to a hand pump on deck. They are cleaned out periodically and painted with lime or cement wash. Small tanks are galvanized. They are boxed in to protect them from cargo, and the cargo from damage by sweat. They are sometimes seated on wood chocks, but as these are liable to decay, a proper angle-bar seating should be provided, elevated if practicable, so as to give access below. They are secured in place by uprights, brackets, or by encircling bands of iron.

Art. 437. To drain water from the decks, all are provided with scuppers, and in high-class vessels the deck houses and other erections are provided with **scupper pipes,** to convey water from their gutters to the gutter waterway of the upper deck. As described in Art. 169, the upper-deck scuppers are usually mere apertures cut in the upper part of the sheer strake, but in passenger vessels, to prevent dirty water from trickling down over the cabin windows, scupper pipes are led down and passed through the vessel's side below (see Fig. 22, Plate 15). The pipes are usually of galvanized iron, and, to avoid choking, are made of large size, 4 or 5 inches. Scupper and water-closet **soil pipes,** if well above the waterline, may be of lead, but the elbow at their lower ends, where they bend round and connect to the shell, should be of cast steel, brass, or gunmetal; to bolt the lead pipe to the side would be very improper, for a stab with a boat-hook, from the outside, might pierce it. In ordinary cargo boats the bends are of cast-iron, but this is inferior to gunmetal, for it is brittle, and might be fractured by pressure from quay walls or from other vessels alongside.

Pipes which discharge near or below the waterline should be of iron, cast or malleable, for if of lead they might be damaged and admit water; rats, for instance, have been known to gnaw holes in lead pipes, and if a fire should occur the pipes would melt. Lead pipes should be securely boxed in, so that they may not be damaged by cargo, and those which pass through coal bunkers should be cased in with sheet iron.

Water does not often wash about on a **lower deck**, but small quantities may collect, through sweating or leakage from the deck openings above. To remove this, **scupper pipes** are provided, one at each end of each compartment, or perhaps only one at the lowest part of the deck—on either side. They are usually of lead, about 2 inches diameter, and are passed down the vessel's side to the bilge, the end of the pipe overlapping the cement below the ceiling planking. To avoid boxing them in, they are usually placed out of the way behind the reverse frames. In passenger vessels having 'tween-deck cabins, the lower-deck scuppers are provided with **syphon traps**, so that the effluvium from dirty bilge water may not pass up and pervade the living spaces (Fig. 7, Plate 73). In large passenger vessels, where the second deck is well above the waterline, its scuppers are led through the side, like those of the upper deck; for large quantities of water may get on this deck when it is being washed by hose, or should sea water pass down by the numerous openings in the deck above. These scuppers must be provided with **storm-valves** (Figs. 1 and 5), so that sea water may not dash up the pipes into the 'tween deck space; and all scuppers are provided with deck gratings to avoid choking.

As the **top of a deep ballast tank** forms a deck, provision must be made for the removal of drainage water. In the case of a peak tank, a small well, or pocket, is usually formed in the tank top, and the suction from a deck hand pump led into it. Sometimes automatic float valves are fitted in the tank top, which may pass drainage water into the tank, but which close should water from the tank seek to pass up; these, however, are not reliable. When the space above is not used for cargo, a screwed plug may be provided in the tank top, by removing which drainage water may pass into the tank.

In high-class vessels scupper pipes are sometimes led from the **winch sole** plates, down below the deck, across it and through the vessel's side, to drain away dirty, oily water. The **cabin sidelights** condense water, and they may leak, and when open may admit rain or spray. To collect this water, **drip pans**, portable or fixed, are usually fitted below the sills of the lights; in some cases a small vertical scupper pipe is led from the sill of each light down to a larger, fore-and-aft pipe, which discharges over some adjacent lower-deck scupper; the pipes are, of course, covered in by the cabin lining.

Art. 438. Water-closet **soil pipes** discharge just above the waterline, where they may be washed by the waves; and, to prevent the sea from dashing up, they are provided with **flap or storm-valves** (Figs. 1 and 6, Plate 73). If the water-closets are of double-valve type, an up-draught, whether of air or water, would not pass into the closet, but if the sea were free to rush up the pipe, the sudden pressure might discover weak places or leaky joints. Storm valves are usually so arranged that the flap may be lifted for cleaning from within the ship (Fig. 6); and sometimes to facilitate repairs or cleaning operations at sea, an outer sluice or screw-down valve is provided, this being essential in soil pipes which discharge below water. The lower part of the soil pipes, connecting to the storm valves, should be of iron; lead is permissible only for those pipes which are well above water. In large passenger vessels, where many closets are placed together, the fitting

of numerous storm valves is sometimes avoided by leading the several soil pipes into a large, inclined pipe, discharging through one large valve on the vessel's side (Figs. 2 and 3). The overflow from the sanitary tank may be diverted into this large soil pipe, so as to flush it constantly; and a clearing plug or door should be provided to permit of a rod being passed into the pipe to clear away obstructions. All sharp bends or elbows in soil pipes, or others which may pass solid matter, should be provided with clearing plugs. To prevent foul back-draughts, a single-valve water closet must have a syphon-trap in its soil pipe (Fig. 1); a double-valve one does not require this. Syphon traps are objectionable in that the sharp double bend is liable to choke, and an air pipe must be led from the upper elbow to prevent the trap being emptied by suction. Water-closets which are situated near or below the waterline must be emptied by a force pump, but these are practically only found in yachts. The water-closets for the crew and emigrants are usually mere galvanized iron troughs, under constant flush from the sanitary tank. If wash basins, urinals, or baths discharge into an adjacent soil pipe, syphon traps (with ventilating pipes) must be fitted to the discharge pipes to prevent foul back-draughts (Fig. 2).

Art. 439. The **ashes** which gather in the stokeholds must be thrown overboard; this is usually done by filling buckets, hoisting them on deck up one of the stokehold ventilators (by hand winch, or by a small steam or electric hoisting engine), carrying them across the deck to the gunwale, and tipping them overboard. To prevent them from blowing aft on deck, a portable, **inclined shoot** is passed through the rail or bulwark, its inner end having a wide hopper mouth (see Fig. 2, Plate 59). In passenger vessels, to prevent the ashes from entering the cabin sidelights, the shoot may be extended down the vessel's side, to within a foot or so of the water, the extension being tap-bolted to the shell in a semi-permanent manner. In many vessels the ashes are shot overboard without appearing on deck, through a large inclined shoot (one for each stokehold), about 12 inches square, its upper end being within the fiddley and its lower one passing through the side near the waterline (Fig. 1, Plate 29). As the shoot is subject to the scarifying and corrosive effect of hot ashes and water, it must be of thick material, not less than one inch on the bottom part. They may be built of plates and bars, or a large cast-iron pipe may be employed. The shell plating around and abaft the mouth of the shoot should be doubled, for it also wastes rapidly under the scarifying action of the ashes. In passenger vessels a similar **shoot** is sometimes led **from the galley**, for ejecting garbage, and this one should be flushed from the sanitary tank. An excellent contrivance for ejecting the stokehold ashes, now extensively used in high-class vessels, is shown in Fig. 4, Plate 31.[1] It is a wrought-iron tube, about 6 inches diameter, led from the stokehold platform up through the vessel's side just above the waterline, where it is provided with a storm valve. At its lower end there is a receptacle, or hopper, to receive the ashes, in the bottom of which there is a cock with pipe connection to a steam pump. When the pump is started it throws a powerful jet of water up the pipe, which carries with it both air and ashes from the open hopper, throwing them out many feet from the vessel's side.

[1] *See's Patent Hydro-pneumatic Ash Ejector.*

CHAPTER XXX.

Art. 440. The arrangements for ventilating the different compartments vary greatly; while in high-class vessels they may be extensive and elaborate, in others they may be quite elementary. **Ventilation** may be described as the introduction of fresh air and the simultaneous removal of that which has become hot, moist, or vitiated. Many cargoes are of such a nature as not to be affected by, or themselves affect, the condition of the air surrounding them, and, of course, in such cases, whether or not the holds are ventilated does not matter. Delicate cargoes, however (such as grain and fruit), which are apt to decompose, require for their preservation a constant supply of fresh air, more particularly if they are to be long confined in the hold. Ventilation may not always be beneficial, for if the outer air is warm and humid, and the hold and contents cold, its introduction results in a continuous deposition of its moisture, in the form of sweat. In such cases ventilation may actually be detrimental to the cargo; and, with moisture trickling down the sides of the hull and entering the interstices of the riveted joints, the ordinary slow corrosion of the structure may be greatly accelerated.

Art. 441. Coal cargoes are peculiar as regards **ventilation**, for upon this depends very much their freedom from **spontaneous combustion.** Coal when won from the mine absorbs oxygen from the air (about three times its bulk), and, during the absorption, heat is evolved, which, under favourable circumstances, may become so pronounced as to cause ignition. Freshly made charcoal is very active in this respect, it absorbs about three times as much oxygen as coal, and, if exposed to the air in a heap, will take fire, without fail, in a few hours. It has been ascertained[1] that spontaneous combustion of coal cargoes is most likely to occur under the following circumstances: when the coal is bituminous and is put on board fresh from the pit, when it is broken up small so as to present a large absorbent surface, and when the supply of air is neither too great nor too small. When fire occurs it usually originates in that part of the cargo which is situated under a hatchway, where the tumbling down of the coal during loading has broken it up into small pieces. In sailing-ships making long voyages, cases of spontaneous combustion are not uncommon.[2] In steamers they are even more frequent, but here it is not usually the cargo that takes fire (for the shortness of the passage does not usually give time for the coal to heat), but the coal in the bunkers, where the natural tendency to heat is increased by the warming effect of the adjacent boilers. It is a common incident for a steamer to arrive in port with the machinery bilges and pump suctions choked with the coal dust washed out of the

[1] For some interesting information on this subject see a paper by Professor Lewes, *Trans. Institution of Naval Architects*, 1890, also the report of the *Royal Commission of New South Wales*, appointed in 1896.

[2] According to the *Royal Commission*, appointed in 1875, there were—as far as known—at least 57 coal-laden vessels lost through spontaneous combustion between the years 1875 and 1887.

bunkers by the water poured into them to extinguish a fire. As a bunker space is comparatively small, the seat of a fire may usually be located and the fire extinguished before serious damage is done; this being limited, as a rule, to a few burned ceiling planks and perhaps one or two buckled plates and bars. In warships and high-class merchant vessels, the chance of the coal in the bunker taking fire is provided against by insulating the bunker bulkheads where they fall close to a boiler (Fig. 11, Plate 76), and by fitting tubes in the bunkers (projecting inwards from the bulkhead), into which thermometers may be thrust to ascertain whether or not the coal is heating, and thus permit of early preventive measures. Similar tubes are provided with coal cargoes, one or two being passed down amidst the coal at each hatchway.

Heating of coal cargoes may be prevented either by supplying no air at all, and thus providing no oxygen for absorption, or by supplying it in such large quantities, and so continuously, through every part of the cargo, as to dissipate heat as soon as generated. The first plan could be carried out by simply closing all deck openings. The second is impracticable, for with ordinary means of ventilation it would be impossible to send quantities of air continuously through every part of a densely packed mass of coal, weighing perhaps many thousands of tons. When the hold is ventilated in the usual way by cowls, which may be inoperative in heavy weather, the supply of air may be just sufficient to supply the necessary oxygen to further the preliminary heating. The plan of closing all deck openings, although it may have much to recommend it, has not met with approval, for it is urged against it that it would allow the accumulation of explosive gases. The plan generally adopted is not to attempt to force fresh air through the cargo, but merely to pass it over its surface below the deck, so as to remove any gases that may rise upward from the coal. This **surface ventilation** is generally adopted in the coal bunkers of both merchant vessels and warships. It should be observed that cases of explosion, unlike spontaneous combustion, are rare; when a cargo has once taken fire, however, the conflagration is accompanied by frequent explosion, a circumstance which makes it difficult and dangerous to attempt to extinguish it.

Art. 442. The provision of at least two openings, the one to act as **inlet** and the other as **outlet**, is a fundamental feature of all ventilation. Of course, one large opening might serve both purposes, for the air would pass in at one part and out at another, but the interchange is greatly facilitated by dividing the opening with a vertical partition or screen, for then the in and out currents (the air itself will constitute the one opening an inlet and the other an outlet) do not clash and obstruct one another.

For the ventilation of the holds **bell-mouthed** or **cowl ventilators** are universally employed (Fig. 1, Plate 75). When turned to face the wind they act as powerful **down-casts**, and when reversed they form **up-takes**, for as the wind rushes past the projecting lip it draws with it, or induces, an upward current in the tube. Sometimes, to increase the induction and up-draught, a trumpet-like tube is fitted through the back of the cowl, to act as a central air blast (Fig. 4). In fine weather, with a good breeze of wind, cowl ventilators are most efficient, but when spray is flying over the ship it becomes necessary, in order to prevent it from entering the ventilators, to turn them all with their backs to the wind, when, of course, with all acting as up-takes, the ventilation becomes very poor. In very heavy weather it may cease altogether, for, to avoid the danger of the cowls being swept away, they are then unshipped and their coamings closed with watertight plugs. Ordinary cowl ventilators are made of thin sheet iron and

have no great strength; their tubular formation, however, lends them strength, and if raised sufficiently high above the sea level, the precaution of unshipping them is not often required, but, to prevent water from entering and passing below, it may be necessary to close their mouths with tarpaulin covers. The tubular derrick posts now commonly fitted in cargo steamers (Figs. 4, 5, and 6, Plate 61), form most excellent ventilators, for they are exceedingly strong, and as they stand some 15 or 20 feet above the deck, a short cowl, or mushroom ventilator, placed at the top, enjoys almost perfect immunity from sea water. Fig. 6, Plate 75, shows a cowl ventilator designed to prevent the passage of water into the hold;[1] if water enters its mouth, it falls upon the sloping baffle plate and flows out through the side port, which, being provided with a somewhat weighty flap, will not open to the light pressure of a current of air. Another is shown in Fig. 3; here the front part of the ventilator tube is extended upwards into the cowl, and forms a convex shield, so that should spray strike it, it is thrown against the sides of the cowl and trickles out.

Art. 443. In **cargo steamers,** at least one cowl ventilator is fitted at each end of each hold, the one to serve as down-cast and the other as up-take (Plate 109). In many cases two pairs are provided for each hold. If a thorough ventilation of the cargo is required, one of the two ventilators should be extended to the bottom of the hold, for when both stop at the deck, the fresh air, choosing the shortest route to the outlet, passes straight fore-and-aft over the top of the cargo and leaves comparatively undisturbed the air at the bottom of the hold; but this is rarely done, for, with most cargoes, surface ventilation is found to be sufficient, and, with densely packed cargoes, the air might not find a sufficiently free passage through it, from the inlet to the outlet. Sometimes with cargoes requiring very thorough ventilation, a trunkway having air holes in its side is led fore-and-aft at the bottom of the hold, and a down-cast ventilator is led into it, so that the air, passing along the trunkway and escaping by the apertures, may be distributed all over the bottom of the hold. This arrangement is sometimes adopted to distribute cold air in holds which carry frozen meat. When there is a 'tween-deck space, down-cast and up-take ventilators must be provided for it as well as for the hold. Sometimes for this purpose a separate pair of cowls are fitted, but more usually one pair is made to serve both spaces, by making the 'tween-deck tube of smaller diameter than the one above (Fig. 1, Plate 75). Sometimes one cowl ventilator is made to serve both as an up-take and down-cast, by forming it in the double-fashion shown in Fig. 5.

Sailing-ships do not usually require such thorough ventilation as steamers, for as they make long passages they do not carry goods of a highly perishable nature. They have usually one or two cowl ventilators at each end, and one amidships. The latter is placed over the pump shaft, or well (for which it forms an entrance), so as to pass air to the bottom of the hold. Sometimes, at each hatchway, a large mushroom ventilator is fitted in one of the hatches. The **masts** form most efficient **up-take ventilators,** for when heated by the sun they are, in effect, tall chimneys. The mast head is covered with a sheet iron hood, open around the edges; and, of course, suitable apertures should be provided at its heel (see Fig. 17, Plate 75).

If the cargo is one that would benefit from ventilation, the hatches are removed whenever the weather permits; and in passenger vessels, or those engaged in the **fruit trade, grated hatches** are provided, which, while opening the hold to the atmosphere, may be quickly and securely covered

[1] Boyle's patent ventilator.

by tarpaulins; or in rainy weather the tarpaulins may be erected like a tent over the open hatchway. A useful means of ventilation is provided by canvas wind-sails, *i.e.* cowl ventilators made of canvas (Fig. 11, Plate 75); in fine weather they may be suspended over a hatchway, by lines from aloft, with their tails passing down into the cargo in the hold, or along the 'tween-decks to ventilate the passenger spaces.

Art. 444. The well-known **mushroom ventilator** is largely employed for ventilating cabin spaces (Figs. 14 and 15, Plate 75). It forms an active up-take, for as the wind whistles past the base of the hood and becomes rarefied on the leeward side, it induces an upward current. The up-draught may be regulated by screwing the hood up or down, and as this overlaps the open end of the tube, it prevents the entrance of rain or spray. If the deck is awash with water, the hood may be screwed down tight, and it may be provided with a bull's-eye to shed light below. In passenger vessels, special ventilating casings may be fitted over the cabin spaces, and sometimes several large mushroom ventilators are placed on the top, so that an upward current of air may be maintained even in the heaviest weather (Fig. 21). The warping bollards are sometimes made to serve as ventilators, by providing them with mushroom caps (Fig. 14, Plate 59). **Goose-neck or swan-neck ventilators** (Figs. 16 and 19, Plate 75) also serve as up-takes, but, in this respect, they are not so active as a mushroom. They are largely employed for ventilating storerooms and other small spaces below. When the deck is awash with water the open end is plugged up, or covered with canvas, and, as described in Art. 427, automatic float valves may be fitted to those which cover the air pipes to fresh water tanks (Fig. 19). Mushroom and goose-neck ventilators are made of cast iron. The up-take ventilator, shown in Fig. 8, is very commonly adopted in passenger vessels; by closing one of its mouths with a plug it becomes a down-cast. The one shown in Fig. 10 is provided with vertical slots, which are so masked by strips of metal that the wind can only whistle past them tangentially, and, as a result, an upward current is established in the tube. They are often fitted in passenger vessels which navigate smooth water. Another good up-take ventilator is shown in Fig. 12. The small up-take ventilator shown in Fig. 13 is sometimes fitted on the outer wall of a deck house (where it catches the wind), to ventilate the cabins within or below.

Art. 445. The **ventilation of passenger vessels** is a subject demanding special attention. Compared with the rooms of a house, the cabins or state rooms are very small, about 6 or 8 feet square, and yet one may be made to serve as bedroom for two, three, or even four persons. A large window cannot be opened top and bottom as in a house, but very commonly the only means of ventilation is apertures in the cabin sides, opening into a narrow passage way, which, in heavy weather, when all deck openings are closed, may itself become as stuffy as the cabins. As a natural consequence, the air, especially in cabins situated low down in the ship, may become hot, foul, and ill-smelling, conditions which would not be tolerated for an instant on shore. In high-class, modern vessels the greatest care is observed to secure good ventilation, and often successfully.

There are two classes of ventilation, "**natural**" and "**mechanical.**" The former may be defined as a circulation of air brought about either by the natural tendency of hot air to ascend and give place to heavier, cold air, or by the currents which may be established by the wind blowing past the ship. Mechanical ventilation is a circulation induced by fans, blowers, or air blast. In fine weather, when numerous deck openings, sidelights and ventilators may be kept open, ventilation by natural means may be

all that is desired, but in stormy weather, when large numbers of these openings must be closed, the circulation may become sluggish and inadequate. Nevertheless, by a careful design of the cabin spaces, deck openings and ventilators, ventilation by natural means alone, may, except in the tropics, be all that is desired; and in large, modern, passenger vessels it is endeavoured to secure this result.

Notice briefly the general system of **natural ventilation** adopted in **large passenger vessels.** The passage ways alongside of the 'tween deck cabins form natural air ducts, and, having provided for their thorough ventilation, that of the cabins is at once secured by providing apertures at the top and bottom of their sides (as described in Art. 350, and illustrated in Figs. 14, 16, and 17, Plate 56). The passage ways may be ventilated in several ways; they generally communicate with an open vestibule, having a staircase to a deck-house or companion on the upper deck through which air may pass either up or down; or a long dwarf skylight may be placed over them (as shown in Fig. 5, Plate 8, and Plate 107), to admit both light and air. Passage ways on a lower deck may be ventilated and lighted by doubling the walls of the machinery casing, locally or extensively, so as to form narrow ventilating shafts (as described in Art. 225 and illustrated in Fig. 5, Plate 8, and Plate 107). These make excellent up-takes, for the air within them, being heated by the hot inner wall, tends naturally to ascend. Their tops may be covered by hinged skylight flaps, or by a fixed cover and glazed mushroom ventilators. Fig. 21, Plate 75, shows a central trunk ventilator, for ventilating passenger accommodation in the upper and lower 'tween decks. Very commonly, when there is a deck house over 'tween deck cabin spaces, instead of fitting dwarf skylights, which occupy deck space, special **ventilating windows** are fitted in the coaming of the house, through which light and air may be transmitted below (see Fig. 5, Plate 76). If the coal bunkers are filled from the upper deck through circular shoots, those which traverse the passage ways are made portable and are only fitted during the coaling; and if, in fine weather, flush gratings are fitted in their circular deck holes, excellent ventilation is at once secured. Passage ways are also ventilated by small cowl ventilators, which may send air into and along a small trunkway or conduit, having openings at intervals, with sliding shutters or louvres to regulate the draught (Fig. 18, Plate 75). Cabin spaces, storerooms, etc., in the lower 'tween decks are often ventilated through trunkways formed between the vessel's frames (Fig. 16), by fitting galvanized sheet iron from reverse bar to reverse bar, and fitting over them, in the gutter waterway of the upper deck, large goose-neck ventilators, or, if a down-draught is required, small cowl ventilators.

In large passenger vessels a thorough **ventilation** of the numerous **water-closets** is an important matter. If not situated close to the vessel's side, they are very commonly placed alongside of some portion of the extensive machinery casings, where excellent ventilation may be afforded by the ventilating shafts just described (Fig. 5, Plate 8, and Plate 107). When these are extended to the top of the fiddley, high above the promenade deck and sea level, they may be kept open in all weather, and carry away, unobtrusively, all foul air. When cabins are ventilated by the same shaft as the water-closets, division plates or special trunkways must be introduced to prevent the entrance of foul air.

Art. 446. The cabins next the vessel's sides and the athwartship passage ways between them, may be well ventilated by the **sidelights,** but unless these are of the special type described in Art. 453, they cannot be depended upon, for unless they are high above the water level, they can

only be opened in the finest weather. In a small cabin, an open sidelight may cause an objectionable draught; but in tropical climates draughts are sought after, and in the case of the side alleyways and large open deck spaces occupied by emigrants, the draught through the lights is artificially increased by inserting protruding **wind-catchers** (Fig. 9, Plate 75), which catch the wind and send it inside as a pleasant breeze. Sometimes a similar purpose is secured by pivoting the lights, so that they may revolve and lie in an athwartship plane, the one half projecting beyond the vessel's side (Fig. 7); and, by sloping them forward or aft, they may either send air within, or suck it out by induction.

Art. 447. The **heat from the vessel's funnel and boilers** is very commonly utilized as a means of ventilating the contiguous spaces of the hull. If a large pipe, or trunkway, be led from the contiguous 'tween-deck space into and up the funnel, the air within the latter portion, becoming heated, would naturally ascend, and, by drawing after it the cold air from the 'tween-deck space, give continuous ventilation. In practice, the pipes do not enter the funnel; sometimes they are passed up between its double walls (a funnel has always an outer shell, to reduce radiation), but more usually it is found sufficient merely to lead them up within the casing, for the air here, being heated by the funnel and boilers, is always very hot (Fig. 11, Plate 76). Although an up-draught so established is positive and continuous, it is not very powerful, and is, therefore, only applicable for ventilating contiguous spaces, for if the conduit pipes were long, the current through them would be sluggish. This system of **funnel ventilation** is chiefly used as a means of ventilating the coal bunkers; those in warships are always so ventilated, a large tube being led from the upper part of each bunker into and up the casing near the funnel. Sometimes in merchant vessels the boiler-room tank of the double bottom is so ventilated. It is, of course, the heat from the boilers and funnel that makes the shafts described in Art. 225 such excellent up-take ventilators.

Art. 448. In passenger vessels, which pass through or trade in the tropics, **mechanical ventilation** on a more or less extensive scale is now always provided. And in other vessels it is usually provided for cabins situated low down in the hull, where, in rough weather, when numerous openings may have to be closed, or when lying in harbour with no wind blowing past the ship, natural ventilation might almost cease. In warships the numerous small watertight compartments, cut off from the atmosphere by the continuous watertight protective deck, must be ventilated by mechanical means; in these vessels, therefore, mechanical ventilation on a large scale is essential.

In passenger vessels the mechanical ventilation is now usually provided by **electric fans** or **blowers**. All modern steamers have dynamos for electric lighting, so that, with little extra provision, electric power may always be available for driving the fans. These may be arranged to exhaust air from the passage ways and send it into the machinery casing, or up any other shaft or ventilator specially provided or otherwise. It is advantageous to blow the air into the machinery casing, for it promotes, at the same time, ventilation of the hot engine-room. As already noticed, if the passages between the cabins are thoroughly ventilated, the ventilation of the latter is at once secured, simply by providing apertures in their walls. In some cases, the better to regulate the passage of air through the cabin sides, a small 6-inch electric fan is substituted for the usual fan-light or grating over each doorway, which may be switched off and on by the occupant of the cabin. Electric blowers may also be fitted within the large skylights of the saloons, etc., to assist the upward out-flow of heated

air. In Atlantic cattle vessels the upper 'tween decks is usually set apart for cattle, and if not thoroughly ventilated, it would become hot and foul; numerous, large, cool ventilators are, therefore, provided, and in some cases electric fans are fixed in the base of the up-takes.

In temperate climates the **ventilation** is sufficient if it merely removes or prevents the sensible formation of heated or vitiated air. In **tropical climates**, however, this does not suffice; here it is necessary for the comfort of those on board that there should be a constant movement of the air, such as is secured by the well-known punkah of the East. This is readily accomplished by means of small electric **air propellers**, or **bees-wing fans**. They may be placed anywhere; very commonly they are fixed under the roof of the saloon, and sometimes small ones are placed in the sleeping cabins. In some vessels a machine-driven **punkah** is provided, formed by a small shaft, placed under the beams of the cabins, furnished with projecting arms on which there is stretched a web of canvas. The shafts are led to the engine-room casing, and are made to oscillate through an angle of 90 degrees, by a suitable connection to a reciprocating part of the main engine, or by a small engine provided for the purpose.

In some vessels the mechanical ventilation of the cabins on the lower deck is accomplished by means of a large **centrifugal fan**, or blower, placed in or near the machinery casing. This exhausts, or propels air from, or into, an **air trunk or conduit** of rectangular section, which is led along the passage ways under the beams (as in Fig. 18, Plate 75), or through the cabins below the berths, where it is out of the way, and is provided with louvres to regulate the supply of fresh air into each space. The connection of the fan to the trunkway may be so arranged that, by turning a flap valve, air may either be drawn from or sent along the trunkway. In warships this is the method of ventilation generally adopted for the compartments below the protective deck.

The **air-blast or induction system of mechanical ventilation**[1] may be described as follows. An air-compressing engine, placed in or near the engine room, pumps air into a receiver, to a moderate pressure of about five pounds per square inch. From this reservoir a pipe (about 3 inches in diameter) is led fore-and-aft in the 'tween decks, having small $\frac{3}{4}$-inch branches to the bases of the various cowl ventilators (Fig. 2, Plate 75), which may or may not be connected with a trunkway. The end of each branch is provided with a nozzle, so designed that the compressed air, escaping in an annular jet up the ventilator, offers, with a minimum volume of discharge, a maximum surface to the surrounding air. When the jet is turned on, the still air within the ventilator receives a powerful impulse, and is forced upwards—or downwards—almost as if driven by a piston. So efficient is the inducing power of these jets, that for each cubic foot of air that escapes therefrom, fifty cubic feet of still atmospheric air are carried with it. In some vessels the arrangements for ventilating on this system are very extensive, being capable, it is said, of inducing a current of air having a volume of over 13,000,000 cubic feet per hour, or some fifteen or twenty times the total internal volume of the hull.[2] The very thorough ventilation so secured is particularly useful in Eastern-trading vessels, which, when carrying delicate cargoes, may pass quickly from a cold to a hot climate. With ordinary systems of ventilation, the amount of air blown through the holds is so small that when the vessel, loaded in a cool port, meets for the first time with hot weather, the introduction of the hot, moisture-laden air to the cold holds at once results in extensive

[1] *Lees Anderson's, or Green's system.*
[2] *Engineering* for November 27, 1891.

sweating; if, however, as the hot latitudes are approached and entered, air is passed through the holds, continuously, and in immense volumes, it not only ventilates, but, by quickly raising the cargo to its own temperature, precludes sweating.

Art. 449. The question as to which is the more efficient, the **exhaust or pressure systems** of mechanical ventilation, is one not readily decided. There can be little difference in the results one way or the other, for, of course, for every cubic foot of air which enters one must pass out. As heated air tends naturally to ascend and lie under the roof, the outlet should be placed at the top and the inlet at the bottom, and the one as remote from the other as possible. When the air enters by a single aperture, it is more likely to stir up the contained air and create a draught, pleasant in hot weather but not so in cold. If it be required to remove foul air which tends to lie at the top or bottom of a compartment, then the exhaust method is the more efficient, for, with the exhaust tube led to the spot where the gases are most likely to accumulate, they are drawn off first, without commotion. This principle is observed in the **ventilation of oil steamers.** Upon emptying an oil tank, quantities of gas are given off from the oily walls, and as this gas is about three times as heavy as air, it accumulates and lies at the bottom. To remove it the simple plan is adopted of using as conduits the large oil suction pipes (usually about 10 inches in diameter); after the oil is withdrawn the impure air is made to follow it by simply continuing the pumping, but, to secure a rapid current, a centrifugal fan, or blower, is substituted for the ordinary piston pumps.[1] The ventilation of the tanks of oil steamers is an important matter. When mixed with air in certain proportions and exposed to a naked light, an inflammable gas will explode with violence—a phenomenon commonly observed in the small explosion which occurs on lighting or extinguishing a gas stove. In consequence of men entering an empty and improperly ventilated oil tank with naked lights, explosions have sometimes occurred, killing the men and wrecking the ship. Now, however, by cleaning the tanks with hot steam, and by adopting a system of continuous ventilation, the air may be kept so fresh and pure that delicate cargoes, liable to be damaged by smells, may be carried without deterioration.

Art. 450. A special ventilator is provided for the shaft tunnel, usually a small cowl having a direct lead from the upper deck; the tunnel, of course, being a confined space, opening into the hot engine room, is apt to become hot and foul, especially if lighted by oil lamps. If, through fracture of the tail shaft, the tunnel should fill with water, so also would the ventilator tube; it should, therefore, be strongly made, of thick material, especially if not protected from cargo by an outer wood casing. In old ships the **tunnel ventilator** is often defective; it may be made of thin uncaulked sheet iron, and be corroded through in holes or broken by blows from cargo. The only means of ventilating the double bottom is the small air pipes, but, as a rule, the air within an empty tank is quite fresh, for it is renewed at each filling, and the water is not often dirty. In the case of the **peak compartments** and **double-bottom tanks**, which may be empty for a long period, the air sometimes becomes dangerously foul. When entering to inspect them it is a common occurrence for the light to go out, owing to the presence of carbonic acid gas; this is a timely warning, for a man may breathe air which is too foul to support the combustion of a candle. Nevertheless, fatal accidents have sometimes occurred, and it is, therefore, very necessary to make sure, before entering

[1] This system of ventilating oil ships is described in a paper by Messrs. Terry and Flannery in the *Trans. Institution of Naval Architects*, 1894.

these confined spaces, that the manhole covers have been removed some time previously.

Art. 451. As regards the **ventilation of the machinery space,** large volumes of fresh air are required to carry away the air which has become heated by contact with the hot engine and boilers, and to support the combustion in the furnaces. If the ventilation is inferior the machinery space becomes unbearably hot; in the tropics it may attain a temperature of 150 degrees or more, when, of course, the labour of stoking becomes exceedingly trying. The stokeholds are ventilated by large cowls, two in each space (Figs. 1 and 5, Plate 109, and Fig. 4, Plate 31); they extend down to within about 7 feet of the stokehold platform, so as to supply the fresh air where needed, *i.e.* near the furnace doors and where the men are at work. More air passes down the ventilators than is required for the furnaces or funnel draught, and the surplus, always accumulating at the lower part of the stokehold, displaces or forces upwards the heated air, which escapes through the open fiddley gratings. The cowls are strongly constructed, and as they are elevated on the top of the fiddley casing, they can withstand almost any weather. They sometimes pass water below, but in the stokehold this does not matter; as the fiddley gratings, however, may pass large volumes, it may be necessary to cover them in heavy weather (Art. 222). To secure the maximum draught the cowls must face the wind, and in large vessels, to avoid the necessity of going on deck to adjust them, they are geared, so that they may be rotated from the stokehold, either by an endless chain passing round the lower part of the cowl or by pinion or worm gearing. To reduce friction, large cowls are provided with casters or roller bearings. The engine room is usually ventilated by two or more cowls, extending well down towards the bottom, the hot air escaping through the skylight.

If there is no wind on deck, the current of fresh air passing down the stokehold ventilators is slow, for it is only brought about by the natural tendency of heated air to rise, and of cold to descend. All the air which passes up the funnel must first descend through the stokehold ventilators, and if the downward current of fresh air were only caused by the up-draught in the funnel, the latter would be retarded, the combustion in the furnaces would be sluggish or incomplete, and the stokehold would become unbearably hot. All this is minimized by providing sufficiently large ventilators and fiddley openings; but it may be avoided altogether by assisting the downward current of fresh air by means of centrifugal fans or blowers. In large vessels this method is now very commonly employed; it ensures thorough ventilation and ample air for the furnaces independently of the wind and weather, and it permits of comparatively small fiddley openings and casings, an important matter in passenger vessels where 'midship deck space is valuable. Although the supply of air to the stokehold and furnaces is here established to a certain extent by artificial means, the fact that the fiddley is open precludes the possibility of any actual pressure of air, and, accordingly, the draught through the furnaces and the combustion is natural, and not forced. The expression "**natural draught**" is therefore applicable, but "**assisted draught**" is more appropriate, and is the term generally used, the former being reserved for cases where there are no fans at all.

If, in a stokehold ventilated on the above system, all the outlets excepting the furnaces were closed, then the surplus air sent down by the fans would accumulate, and, by raising the air pressure beyond that of the atmosphere, greatly expedite the rush of air through the furnaces; the fires, in consequence, would be urged, the combustion would be accelerated, and

the steam-raising power of the boilers greatly enhanced. This **closed-stokehold system** of **forced draught** is commonly adopted in warships.[1] In many merchant vessels forced draught is also employed, but here, instead of closing the numerous stokehold openings, which involves many difficulties and objections, the simpler plan is adopted of fitting special airtight doors to the furnaces, and injecting air through them, above and below the fires. Among other advantages, this system [2] admits of the air being heated (by the gases in the smoke box) before it is sent into the furnaces, which greatly increases its effect in promoting thorough and rapid combustion.

Art. 452. Cowl ventilators are made of galvanized sheet steel, from $\frac{1}{32}$ to $\frac{1}{16}$ inch thick. The thickness is usually specified in wire gauge. The head, or cowl, is composed of segments, hammered to shape and riveted together. The lip is strengthened by a stout beading. The fixed, or coaming, portion is strongly made, of steel plating $\frac{1}{4}$ to $\frac{3}{8}$ inch thick, rolled into a tube and riveted with an inside strap (Fig. 1, Plate 75). It is riveted to the deck plating by an angle bar, and if the latter is riveted first to the tube, the camber of the deck must be taken into account. With a wood deck it is often merely bolted to the planks, a flat iron ring being fitted below to take the bolts, but Lloyd's rules now require a deck plate to be provided (Fig. 3). The cowl ships over the coaming, and it may rest on the toe of the deck angle (Fig. 5), but it is better to provide a special bearing ring (Figs. 1 to 3). The coaming should stand at least 3 feet above the deck, to minimize the chance of a downpour of water, for, of course, if solid water got on deck, the loosely fitting cowl would not form a watertight cover to the coaming. Sometimes it is made 4 or 5 feet high, so that, by means of an adjustable bearing ring, the cowl itself may be raised or lowered; this is often convenient when cargo or cattle are carried in a temporary shelter on the upper deck, for it permits of the tops of the ventilators being raised well above the obstruction. The 'tween-deck portion of a ventilator tube may be fixed or portable (Fig. 1). Fixed ones, if not boxed in, should be of stout material.

Ventilating trunks, such as are employed for mechanical ventilation, are usually of galvanized sheet iron, riveted with a longitudinal seam; the different lengths may connect by shipping into one another (B, Fig. 18, Plate 75), but it is better that they should be connected by flanges (A, Fig. 18). They are of rectangular section, about 9 or 12 inches square; if placed below the beams they are made broad and shallow, to maintain the head room. If there are louvres all along the trunk, it may be tapered, becoming smaller the further it is removed from the fan. These trunkways, of course, should not pierce watertight bulkheads; in warships they often do, but, to prevent water from passing through them from one compartment to another, efficient automatic float-valves are fitted as shown in Fig. 20.

Art. 453. The **sidelights, side-scuttles, or port-holes** vary greatly in design; one of ordinary type is shown in Fig. 4, Plate 76. The fixed frame is riveted to the shell plating, the glass-holder frame is hinged to it and is closed watertight by pivoted bolts (one in small lights and two in large) which press a V-shaped projection on the one frame against an indiarubber packing ring in the other. To protect the glass in heavy weather against blows from the waves, a portable plug or shutter, in the form of a disc of cast steel or malleable cast iron, is placed outside, being

[1] The air pressure in a closed stokehold does not usually exceed about 1½ oz. per square inch, or what is represented by a 2-inch head of water.

[2] *Howden's system.*

held in position by a small projecting lip on the fixed frame. This plug is not watertight. As a provision against the breaking of the glass and the entrance of sea water, an inner watertight cover, having an indiarubber packing ring, is provided; it is hinged to the fixed frame and is hove up by a tightening screw. These plugs and covers are only used in heavy weather, at other times they are stowed away near the light. The plug is not always provided.

Sidelights vary in diameter, from 6 inches in a small cargo vessel, or in the crew's quarters, to 15 inches in the saloons of large passenger vessels, the average size is 9 or 10 inches. They must be massive and strong, for they are subject to severe blows from the waves. The glass varies in thickness from $\frac{1}{2}$ inch in a 6-inch light to $1\frac{1}{4}$ inches in a 14-inch one. But although so thick it often cracks, due to defective glass or to undue local stress from the tightening screws and insufficient massiveness and rigidity in the brass frame holding it. The brass used for sidelights is often of inferior quality, and the frames of too slender a design, and as a consequence they sometimes fracture. In warships tough bronze or gunmetal is used for such parts. Those sidelights at the bow and stern which come within the range of the cables, should be protected by external iron bars (see C, Fig. 1, Plate 76). In high-class vessels, *wriggles* or *eyebrows* are fixed over the lights, to throw off water as it trickles down the vessel's side (see A and B, Fig. 1). In others the upper part of the frame usually projects about half an inch beyond the shell plating. When there is an insufficient means of lighting cabin spaces, prismatic glass deck lights are sunk in the wood deck (Fig. 2). They are held down by a brass or steel frame, and are made narrow and long, so as not to cut more than two deck planks. They are made prismatic the better to disperse the light.

Fig. 3, Plate 76, shows a high-class light; when shut it is held in place by the five catches C; these engage with wedge-shaped projections on the frame A, this frame being revolved slightly by the handle B. By a small movement of the handle, therefore, the light may either be firmly secured or released ready for opening.

Fig. 5, Plate 87, shows a **patent ventilating sidelight,**[1] much used in high-class passenger vessels for lights situated near the waterline. It is designed to give **continuous ventilation,** without draughts and without risk of an inflow of water, even should it be entirely submerged. It will be observed that when the glass is closed (the plug being removed) air is still free to enter, as shown by the arrows; water cannot pass, however, for if it entered the chamber A, the cork float-valve B would at once rise and block the passage, and even if by chance this valve failed to rise, there is a second one above it, and it is very improbable that both would fail to act. To give a sufficiently large air passage, with a minimum inward projection of the light, there are two lower valve chambers abreast and two upper. The air passage may be closed watertight by the hinged lid, and metal plugs and covers are provided to protect the glass or take its place should it break. The upper valve chamber of these lights forms a suitable termination for the air pipes from fresh-water tanks, or for ventilating pipes from lower-deck spaces or coal bunkers. Large window lights for fixing to the coaming of a deck house (as in Fig. 5, Plate 76) may also be arranged with float valves, as above for giving continuous ventilation to the cabin spaces in the 'tween decks, even in heavy weather when the deck is awash with solid water. Fig. 6, Plate 87, shows a large window for the side of a deck house; here float

[1] *Utley's port-hole ventilator.*

valves are dispensed with, and baffle plates substituted, these being sufficient to prevent water being blown through the air passage. Automatic float-valves may be arranged in connection with a cowl ventilator, as shown in Fig. 3. Ordinarily, this ventilator acts as a down-cast, but in heavy weather, when its mouth may have to be closed, it at once becomes an active up-take, and one that will not pass water below, though the deck be flooded. It stands low, and is strongly made of cast steel, so as to withstand the heaviest weather without danger of being swept away. These ventilators are fitted on the forecastle deck of some large Atlantic liners.

Another **improved sidelight**[1] is shown in Fig. 4, Plate 87. It will be observed that when closed it is hove up by an *inward* pull, so that a blow from a wave does not, as in an ordinary light, tend to strain the bolts, break the glass, and burst the light open, but presses it more tightly home against its seat. The light is pivoted instead of hinged; to open it, it is first pushed bodily outwards, the pivots sliding in transverse grooves, and it may then be rotated, so as to lie athwartship, and act either as an inlet or outlet, according to the direction in which it is sloped. Should ventilation without draught be desired, it is placed as in Fig. 4, the projecting ledge R then acting as a baffle, preventing a through draft and the entrance of rain or spray. The deck-house window, shown in Fig. 6, is also closed by an inward pull of the bolts, and, when shoved bodily outwards, affords ample ventilation without any chance of rain or spray entering the cabin space.

Art. 454. In passenger vessels the sides of the **machinery casings** in the living spaces, if not doubled to form a ventilating shaft, must be **insulated** to prevent the free passage of heat. This is done by fitting wood or galvanized iron sheeting, 3 or 4 inches from the casing, and filling the space between with silicate cotton or asbestos fibre (Fig. 11, Plate 76). Iron sheeting may be fixed by small screws to stiffeners of Z section, or studs may be fixed in the plating, having sleeves or collars to hold it at proper distance. The casings in the upper 'tween decks of cattle ships are usually insulated in a similar way. If a **lower deck**, on which passengers are berthed, extends over and close to a boiler, it is **insulated** by fitting silicate cotton below, between the beams, and sheet iron to hold it in place (Fig. 11); and sometimes this is done when coal is carried above, to prevent dangerous heating. If the steam pipes passing from the boilers to the engine traverse a coal bunker or living space, they are enclosed in an iron trunkway, and this should be filled, around the pipes, with insulating material, to prevent heating of the coal or living space. And when a coal bunker bulkhead falls within a few inches of a boiler, it is well to insulate it at this part (Fig. 11).

Art. 455. All large, ocean-going passenger steamers are provided with **refrigerating machinery and insulated chambers** for carrying the fresh meat required for consumption during the voyage; and many steamers are specially arranged to carry **cargoes of frozen meat**, the holds devoted to this purpose being insulated and kept at a freezing temperature throughout the voyage. Insulation may be described as the covering up of all the exposed steel work of the hull with a thick layer of non-conducting material, so that nowhere may the cold air of the hold come in contact with it, for as it is a conductor, and is warmed by the outer atmosphere and sea water, it would rapidly extract and dissipate the cold. The thoroughness of the insulation, or, in other words, the thickness and continuity of the layer of non-conducting material, is a very important matter. If a hold is well

[1] *Utley's pivoted port-hole ventilator.*

insulated, then when it and the cargo (frozen stiff before shipping) are chilled to the required temperature (from 15 to 20 degrees Fahr.), they will remain so, with little necessity for further refrigeration and small chance of local heating, such as sometimes occurs through imperfections in the insulation. If, on the other hand, the insulation is imperfect, the temperature tends constantly to rise, and to keep it down may involve the more or less continuous running of the refrigerating engine, with danger to the cargo through variations of temperature, and considerable expenditure of coal. Of course, should the temperature rise at any time so as to thaw and soften the carcases, the cargo might be seriously damaged; it is rarely, however, that this happens, except locally, under the hatches or where the insulation has become defective, or in corners where the cold air from the refrigerating engine has not penetrated, or in cases where the carcases have been shipped soft and have become so crushed together as to prevent the cold air from circulating between them; this is most likely to happen in the case of the lower carcases in a deep hold.

Charcoal is the **insulating material** usually employed; either the finely divided *flake charcoal* or the coarser *twig charcoal*, both, when well packed, giving equally good results. *Silicate cotton* and *pumice stone* (in fine gravel) are occasionally used; as regards weight and insulating properties they are not inferior to charcoal, and they have the advantage of incombustibility in case of fire. *Felt*, *cow-hair*, *cork*, etc., are often used for insulating small spaces. A commonly adopted method of insulating the hold is shown in Figs. 6 to 9, Plate 76. The layer of charcoal on the ship's side is usually 8 or 9 inches deep (Fig. 8); it is rammed tightly in, to prevent subsequent subsidence and the formation of vacant spaces, this being the most fruitful cause of local heating and damage to the contiguous meat. Silicate cotton does not subside, and in this respect it is better than charcoal. The outer wood lining is covered with sheet zinc, as a precaution against the charcoal running into the air space should the wood become imperfect by decay, or be gnawed through by rats when carrying general cargo. In many cases, however, an air space between the shell plating and the charcoal (as also between the tank top and charcoal) is dispensed with, the charcoal being filled in against the plating. This, of course, is a cheaper arrangement, and, as regards insulation, appears to be no less efficient; it is objectionable, however, in that, should water leak through the ship's side, the charcoal becomes sodden, and is apt to cause rapid corrosion of the vessel's plating and frames. Small 'tween-deck storerooms, such as are provided in large passenger vessels for carrying chilled beef, provisions and fruit, at a temperature somewhat above the freezing point, need not be so thickly insulated, and in such cases soft felt sheeting may be substituted for the usual thick layer of charcoal. The hatches over an insulated hold are formed like boxes, and are filled with charcoal (Fig. 9); and similar hatches are provided over the tank side gutters and manholes in the tank top, to give access to those places. Before insulating a hold, the steel work should be thoroughly cleaned and well painted, for when once covered up it may be many years before it is again accessible for recoating. To permit of its condition, as regards freedom from corrosion, being ascertained from time to time, small portable box-shaped plugs should be provided in the insulating wall, three or four on each side in each hold.

Art. 456. The refrigerating engine is usually placed in the 'tween decks near the insulated holds; in other cases it is placed in the engine room. There are three well-known systems of refrigeration, all of which are used on board ship. The "**cold-air system**" may be briefly

described as follows. In the first place, air, drawn from the hold, is compressed to about 60 pounds per square inch; this makes it hot, and the heat is then abstracted by passing it through a coil of piping surrounded by cold sea-water (and also through another coil surrounded by cold air); when allowed to expand again (against the resistance of a piston) it becomes intensely cold, about − 80 degrees Fahr., and it is then returned to the hold through wooden trunkways.[1] In what is known as the "**ammonia system,**" ammonia gas is compressed instead of air; when compressed and cooled it becomes a liquid, in which state it is passed into a long coil of $1\frac{1}{2}$-inch iron piping placed in an insulated chamber in the 'tween decks, where it is allowed to expand and reassume the gaseous form. In this coil there are several miles of piping, which, by the expansion of the contained ammonia, become intensely cold. Air is then withdrawn from the hold by a fan, passed over the cold coil, and, being thorougly chilled (to about zero Fahr.), is returned to the hold through large wooden trunkways. In the "**carbonic-anhydride system,**" carbonic-acid gas is used instead of ammonia, but it is expanded in quite a small coil, which is placed in a tank filled with brine (a solution of chloride of sodium or of calcium), and as the brine becomes chilled to the requisite temperature, it is withdrawn by a pump and made to circulate through long coils of 2-inch piping, fixed in the hold under the deck and on the upper part of the vessel's sides.

The ammonia and carbonic-anhydride systems are more economical and efficient than the cold-air system; the first, however, is objectionable, in that, should the smallest leakage of ammonia occur, the surrounding air becomes filled with noxious fumes of a most insupportable and dangerous character. The carbonic-anhydride system is advantageous, in that it permits of precise regulation of the temperature, and although an escape of carbonic-acid gas might be dangerous, it is a respirable gas, and, in small quantities, does not cause inconvenience, and, as it is heavy, it lies at the bottom of the compartment.

In all vessels provision is made for **warming the cabin spaces** in cold weather. In large passenger vessels this is usually done by leading copper **steam pipes** along the passageways between the cabins. The pipes vary in size; if large, say $1\frac{1}{2}$ inches, they may be locally reduced at the joints, so as to permit of small flanges, and reduce the stress on the connecting bolts; and the joints may be formed as shown in Fig. 10, Plate 76, so as not to restrict the flow of condensed water. Otherwise small $\frac{1}{2}$-inch pipes may be employed, connecting at intervals to heaters, in the form of copper cylinders, about 30 inches long by 3 inches diameter, or to cast-iron **radiators.** The pipes are connected to the ship's boilers, but as the steam pressure here is unnecessarily high for mere heating purposes, a reducing valve is usually introduced, which closes automatically should the pressure in the pipes exceed a certain limit. To avoid the danger of steam heating pipes bursting, they should be capable of withstanding the full boiler pressure, and should be tested 100 per cent. above it. To remove condensed water, automatic drain-taps are provided. The wood deck below the pipes may be protected from the heat by sheet lead, laid upon thick felt, with a teak covering board over all, and the pipes themselves may be protected by an ornamental cast-iron or brass grating. In some large, modern, passenger vessels the cabin spaces are both heated and ventilated by blowing warm air (heated by passing it over a coil of

[1] If watertight bulkheads are pierced by these trunkways, geared watertight doors must, of course, be provided, to preserve the integrity of the bulkheads, both as watertight partitions and fire screens.

steam piping or a special steam heater) along a trunkway having louvre openings in the various spaces to regulate the draught. In some cases the air is cooled before sending it along the trunkway, by passing it over a coil of piping through which cold brine is circulated. To warm isolated cabins, such as those of the officers on the upper deck, small steam radiators are employed, having a cock by which the occupant of the cabin may regulate the temperature. In the saloons of passenger vessels there is often a handsome fireplace; but in most cases steam radiators are employed, these being more efficient in every way.

CHAPTER XXXI.

Art. 457. The **rusting**, or **corrosion**, of iron and steel is a familiar chemical phenomenon.[1] If immersed in pure distilled water, clean iron will not rust, nor will it in pure air, however humid; to start the process carbonic acid must be present, but when once begun no more is required. As ordinary water and humid air both contain carbonic acid, exposure to either is sufficient to cause rusting; but, of course, if well coated with paint there is no exposure, and, consequently, no rusting. Rusting is the slow combination of the iron with the oxygen of the air; both of these are simple elements, and the resulting compound, rust, is, therefore, an oxide of iron. The formation of rust is gradual; at first merely a brown discoloration, it becomes, later, a thin hard scale. Each new scale or layer adheres to the last, and in course of time they form together a thick, brittle, slate-like mass. **Rust scale** is from four to six times bulkier than the iron from which it is formed, so that when, say, $\frac{1}{2}$ inch thick, it only represents a loss of thickness in the iron of $\frac{1}{8}$ inch or less. Its chemical composition varies, for it may contain a greater or less proportion of oxygen, and may have locked up in it more or less water. In a thick scale, the outer layers are not identical with the inner; the virgin rust next the iron contains a certain quantity of carbonic acid, which it parts with later, so that the same modicum serves to carry on the rusting.

Like all chemical actions, **oxidation** is greatly **accelerated by heat**; in steamers, for instance, the structure of the hull adjacent to the boilers corrodes much faster than other parts, and deck plating, which is exposed to the sun's rays also corrodes quickly. If the heat is very great, iron will combine with the oxygen of the air without any moisture; thus, if heated to a white hot temperature, it will do so so rapidly as to burn and emit showers of sparks, a phenomenon which is simply a rapid oxidation of the iron. If heated red hot, or even to a much lower temperature, the oxidation is also rapid. If a plate or bar is kept at a bright heat it will waste away visibly, thick scales of oxide forming and dropping off at a touch. In practice this has to be provided against; when plates, bars, and rivets are heated, they are not allowed to remain hot longer than is necessary; and plates whose awkward form involves much manipulation at a red heat, are provided $\frac{1}{20}$ or $\frac{2}{20}$ inch thicker, so that, though considerably reduced by oxidation, they may not ultimately be less than the required thickness. A distinct kind of oxide is produced by the application of water to hot steel, it is termed "*mill scale*," "*black oxide*," or "*magnetic oxide*," and is a hard, thin, tenacious, lustrous, blue-black scale. In the manufacture of steel plates, water is thrown upon them during the rolling process, and, consequently, all new plates are covered more or less with mill scale, a circumstance which, as noticed later, has a commanding effect on their rusting tendencies.

[1] For some instructive monographs on the subject of corrosion and fouling, see the *Trans. Institution of Naval Architects*, Mallet, 1872; Farquharson, 1882; Lewis, 1887–9. The *Trans. Institution of Civil Engineers*, Vol. CXVIII., Andrews. The *Trans. American Society of Mechanical Engineers*, Vol. XV., Wood.

Art. 458. The rate of corrosion of iron or steel may be very much increased or diminished by **galvanic action.** If a piece of copper and a piece of iron are immersed in a weak acid, without any metallic contact, both will corrode, if, however, they touch or are placed in metallic contact however indirect, say, by a wire, a galvanic current will at once be established between them, and, as a result, while the copper will cease to corrode, the iron will corrode very much faster, the immunity of the former being secured at the expense of the latter. The arrangement forms the well-known voltaic cell or electric battery, in which the corroding metal is said to be "*electro positive*," and the other "*electro negative*." If zinc is substituted for copper, the conditions will be reversed, for as zinc is electro positive to iron, it will corrode rapidly and the iron not at all. Sea water, owing to its dissolved salts, has the effect of a weak acid, *i.e.* it promotes a galvanic current between dissimilar metals; and this circumstance has an important bearing on the rate and nature of the corrosion of ship's hulls. Other metals besides copper are electro negative to iron, and cause it to corrode; lead, tin, and brass alloys have even a greater effect; and ordinary rust, and especially mill scale, are also electro negative to iron.

The markedly **corrosive effect of brass or copper alloys** upon iron, when in contact with it in sea water, is often observed; under-water sea cocks, for instance, are sometimes of brass, and it is common to find that the shell plating contiguous thereto is deeply corroded. And when the propeller is of bronze, the stern frame and rudder are liable to very pronounced corrosion; this is usually provided against by bolting slabs of zinc ("*zinc protectors*") on the contiguous parts of the hull, for these, being electro-positive to iron, waste away rapidly, in virtue of which the iron enjoys almost perfect immunity from corrosion. Much trouble has always been experienced by local corrosion of the propeller shaft, through galvanic action. As shown in Fig. 11, Plate 29, part of the shaft within the stern tube is covered with brass liners, and as the tube is always full of sea water, a galvanic effect takes place between the brass and the iron, in consequence of which the latter often becomes deeply corroded at points C, close to the end of the liners. The drain plugs fitted in the garboard strake are usually of brass (Art. 429), and it might be expected, therefore, that through corrosion of the plating by galvanic action, they would loosen and perhaps drop out; this is not found to be the case, however, because the plating around the plugs is always well coated with paint, and the plug itself well greased; for, of course, when one or both metals are covered up, they are not in contact with the corrosive fluid, and so cannot set up galvanic action. It is evident, however, that all such under-water brass fittings should be frequently inspected. Clean, metallic **lead** has a markedly corrosive effect on iron, but in practice this is not a source of trouble, because the lead is rendered inactive by the fact of its becoming covered with a coating of its own oxide. The bilge suction pipes, for instance, are often of lead, and although immersed in bilge water and in contact with the steel work of the hull, the latter is rarely found to suffer. The corrosive effect of lead may often be observed in old iron railings; if fixed to the stone work by lead grouting, the bars at their juncture with the lead are sometimes corroded entirely away.

Art. 459. Ordinary rust scale is electro negative to iron, and, consequently, a plate which has scale upon it corrodes more quickly than one which has none. Even when not immersed in water, **a scale of rust accelerates corrosion,** for it has the peculiar property of absorbing moisture (a characteristic described by the word "*hygroscopic*"); on breaking off hard and, in appearance, perfectly dry scale, moisture will

often be observed between it and the iron. It follows, therefore, that while a clean plate may suffer little or nothing from corrosion, one that is covered with scale will corrode continuously, the scale becoming thicker and thicker. For the preservation of the structure, therefore, it is evidently an important matter that scale should be removed without delay. The very erroneous idea is sometimes entertained that the hard, firmly adhering scale which sometimes forms on deck plating and other parts, acts beneficially as a protective covering, and that it is better not to remove it. Loose scale may be removed by the vibratory and concussive effects of hammer blows; if firmly adhering, chisel-faced chipping hammers are employed; and as its removal is then a tedious process, it is not often undertaken. The shell plating, for instance, is not often chipped; in the region of the water-line scale may commonly be observed standing out in thick patches below the paint; to paint over this, as is frequently done, is comparatively useless—it might be likened to varnishing a table while omitting to remove the cloth. When scale gathers on the backs of the reverse frames, it is not easy to remove, and very commonly, therefore, it is not removed; and as this part is out of sight and is difficult to paint, it is often not painted; consequently, the reverse bars usually suffer more than any other parts from corrosion, in old vessels they are generally the first parts to require renewal. Very commonly they are repaired by riveting a flat-iron bar on the exposed flange. If the surface of the steel work is cleaned perfectly free from all foreign matter (a condition seldom secured), and is well coated with good oil paint, it will enjoy immunity from corrosion for many years—assuming, of course, that the paint is not subject to erosive or chemical action.

The **mill scale or magnetic oxide** which is found on practically all new steel plates, is particularly active in promoting, by galvanic action, rapid corrosion of the steel; quite as much so as copper. It is peculiar in that, unlike other oxide, it is impervious to water, so that if it entirely covered a plate it would protect it from corrosion (it has been proposed to protect steel structures by producing artificially a coating of magnetic oxide). In practice, however, it never does form a perfectly continuous covering, for as it is brittle it breaks off locally with the riveting and hammering. Should part of a scale-covered plate be exposed, the steel and the scale, when immersed in sea water, form a galvanic couple, to the rapid corrosion of the steel. If the shell plating of a new vessel is painted before removing the mill scale, it will receive little protection from the paint; for as patches of scale, with paint attached, become loose and fall off, the plates where bare are exposed to widespread galvanic action, and the resulting rapid corrosion accelerates the loosening of the remaining scale.

Mill scale is not found so much on iron plates, nor does it adhere with such persistency as on those of steel; new iron vessels, therefore, were usually quite free from scale before painting. In the early days of steel the peculiar properties of mill scale were not understood or realized, and as no special endeavours were made to remove it, it was a common experience to find, on the first dry docking—perhaps a year after the launch—that the under-water shell plating was entirely devoid of paint and had suffered seriously from corrosion, often of a local and excessive kind. The cause of this was not at first known, it was attributed simply to a pronounced tendency in steel to corrode. The French Admiralty were the first to use mild steel; but, having experienced trouble of this kind, they thought it advisable, in their earlier steel vessels (built in 1873), to use iron for the under-water shell plating.[1]

[1] *Trans. Institution of Naval Architects*, 1881, p. 108.

The corrosive influence of mill scale is now guarded against by removing it, as far as practicable, before finally painting the bottom. To do so by mechanical means is not easy, for it adheres firmly and does not, like ordinary oxide, fly off in flakes when struck by the chipping hammer. The method commonly adopted in high-class vessels, and always in warships, is to immerse each plate in a bath of dilute hydrochloric acid (one part of acid to from 10 to 20 of water), and after steeping for half an hour or longer, wash it with alkaline water and scrub it with machine-driven, revolving, wire brushes. Another excellent method, as yet rarely adopted, is to clean the completed shell with the well-known sand blast; this has the most desirable result of producing an absolutely clean metallic surface, well fitted to take an excellent and enduring coat of paint. In ordinary practice the method usually adopted is simply to defer the painting—of all parts of the hull—till just before the launch, so that the natural process of rusting may cause the scale to drop off, or loosen it, so that it may be readily removed by hammer blows; or the rusting may be expedited by the application of water. Sometimes the painting of the shell is deferred until after the launch (the vessel, when ready for sea, being put in dry dock for the purpose), so that the short period of unrestrained rusting may effect a thorough removal of the scale. And sometimes new vessels are sent a short voyage before painting the bottom. Shipowners generally anticipate poor adhering and protective qualities in the first coat of paint, and dock their vessels for repainting two or three months after the launch; and unless special care has been taken to remove the mill scale, this measure is usually justified by the bare and rusty condition of the plating.

Art. 460. As just noticed, different metals excite corrosion by galvanic effects, but even in a structure composed of one metal there may be feeble galvanic action between contiguous parts, due to slight differences either in their chemical composition or molecular structure. Experiments show, for instance, that steel which has been strained is electro negative to that which is unstrained; when in contact, in sea water, the latter corrodes the faster.[1] It is common to find, in old iron vessels, that while the plates are much corroded the rivets are little affected, and project beyond the surface of the plates; the molecular arrangement of the metal of the rivets is, of course, different from that of the plates, for they are staved up and compressed by hammer blows. A steel plate often corrodes in patches, one part of the surface more than another; this may be due to the presence of mill scale or to differences of composition, due perhaps to slight local variations in the proportion of manganese, through an imperfect mixture of this added element at the steel works (Art. 566). Iron and steel differ both in their chemical and physical qualities, and, consequently, they may set up quite marked galvanic effects; the electro-positive or corroding element is sometimes the steel and sometimes the iron, but more usually it is the iron.[2] The points of iron rivets in submerged steel plates usually corrode faster than the plates, but, of course, no corrosion can occur so long as the surface is well coated with paint.

Ordinary rusting takes place fairly uniformly over the surface of the plating; when due to galvanic action it occurs irregularly, in patches, or still more locally, by **pitting**. A plate, pitted by corrosion, is covered with little hollows, like finger-marks in dough; in a badly corroded plate they may be deep, and, with surface corrosion between, the surface may become very rough and irregular. Pitting is attributed to the presence of small isolated particles of mill scale, which, by setting up galvanic action in the

[1] Andrews, *Trans. Institution of Civil Engineers*, Vol. CXVIII.
[2] Farquharson, *Institution of Naval Architects*, 1882.

immediately contiguous steel, gradually eat their way deeper and deeper into the plate. If, when a vessel goes into dry dock, a pitted under-water plate is examined, there will sometimes be found, over each pit, a small excresence of fresh rust, representing the steel excavated in the formation of the pit, or in new vessels a small blister may be observed, composed of scale or paint, which, when broken, will be found to be full of dirty, rusty water. When cleaning a pitted surface, previous to painting, it is probable that the small particles of foreign matter causing the damage may remain in the hollows and thus carry on the corrosion.

Art. 461. The **comparative rates of corrosion** of the two metals, **iron and steel**, is a subject which has occasioned much discussion and experimental work, but never with very satisfactory or conclusive results. The experiments consist of immersing small plates of ordinary ship iron and of steel in sea water, noticing their weights before and after a more or less protracted period of corrosion, and thus finding, by the loss of weight, which has corroded the more. In some cases the results are favourable to the iron, and in others to the steel; more usually, however, the steel is found to suffer the more.[1] The reason for this lack of agreement lies in the great difference in the quality and composition of ordinary plate iron. Different irons are very differently susceptible to corrosion; a good, pure metal suffers more than a hard and inferior one, and as steel may be regarded as a particularly good homogeneous iron it might be expected to suffer still more. There is, however, often more difference in the rates of corrosion of two different iron plates than in that of a steel plate and an iron plate.

Experience with steel and iron ships shows very conclusively that, under practical conditions, the steel ones suffer the more. Of course, freedom from corrosion can be secured in either case by keeping the structure well coated, and any special care or negligence in this respect far more than outweighs any difference in the inherent tendency of the two metals to corrode. There are certain parts of the hull, however, where the prevailing conditions are such that it is well-nigh impracticable to provide a durable and efficient anti-corrosive coating, and for such parts, therefore, the employment of a metal little susceptible to corrosion would be very advantageous. On the **upper-deck plating**, for instance, a coating of paint has little endurance, for it is exposed to traffic, alternate wetting from sea water, and intense heat from the sun; and, similarly, in the **framework under the boilers**, the intense and continuous heat renders ordinary coverings useless. For these parts, therefore, it is common to substitute iron for steel, in view of its smaller susceptibility to corrosion. Of course, in such cases the thickness is increased proportionately to the lesser strength of the iron, or by about 25 per cent.; and this circumstance is often more beneficial than is the slower rate of corrosion, for it provides a good margin of thickness against its reducing effect. In considering the relative tendencies of a steel and an iron ship to corrode, the fact is often overlooked that, as all structural parts of the former are about 20 per cent. thinner, the same amount of corrosion represents a larger percentage of wasting; thus, while in an iron plate a loss of thickness of 80 per cent. would still leave it intact as regards outline and surface, a steel plate (of the usual 20 per cent. lesser thickness), corroding at the same rate, would have entirely disappeared.

If, when iron is substituted for steel, a high-class material having good mechanical qualities is employed, its adoption may, without doubt, be

[1] An interesting account of some of these experiments will be found in Mr. Farquharson's paper, *Trans. Institution of Naval Architects*, 1882.

advantageous; often, however, its inferior qualities greatly detract from any superiority it may have as regards corrosion. **Iron plates,** owing to their non-homogeneous structure, often corrode in a very irregular fashion. And they often contain **laminations,** *i.e.* loosely cohering layers, which, in the case of deck plates, may present themselves in a most objectionable fashion; for, as the surface corrodes, water, finding its way between the layers and setting up corrosion, may burst them asunder, and raise large blisters, whose sharp, salient edges require constant chipping.

Art. 462. Different parts of the hull are liable in different degree to corrosion; if all were kept well coated, there would be no corrosion, but paint decomposes and loses its protective qualities, and the conditions which cause this are usually identical with those which cause corrosion. It might appear, at first sight, that the **outer surface of the hull** would be more liable to corrode than the inside, for it is constantly immersed in sea water and is only accessible for repainting at intervals, when the vessel goes in dry dock. In reality, however, the reverse is the case, chiefly because of the circumstance that, apart altogether from corrosion, it is imperative that the bottom plating shall be recoated periodically, to prevent *fouling*, *i.e.* the attachment of sea-weed and shells. Accordingly, whether or not the bottom plating requires a fresh *anti-corrosive* covering, it does require, and receives at regular intervals, a fresh coating, for *anti-fouling* purposes. In the early days of iron ships, the necessity for frequent docking and painting was not fully realized; the bottom was observed to foul quickly, but as docking facilities for large vessels were poor, especially abroad, it was sought to secure immunity from fouling by the use of novel anti-fouling paints, often of a dangerously corrosive nature. As a result, the shell plating of vessels which had been abroad for long periods without docking, sometimes suffered seriously from corrosion; in exceptional cases it was so much wasted away that, in scraping off the weed and barnacles (whose growth was usually little retarded by the "anti-fouling" composition), the scrapers actually penetrated the plating.[1] In consequence of these experiences, the under-water plating of the earlier iron vessels was made thick, and towards the bow it was unreduced, for it was anticipated that the fluid friction due to the vessel's motion would here accelerate the wasting tendency.[2] All vessels are now docked and painted at least once a year; high-class liners which pass through warm, tropical waters are docked after every voyage, perhaps four or five times a year. The object, of course, is to maintain a clean bottom, but it results, at the same time, in securing for the under-water shell plating almost complete immunity from external corrosion.

The **shell plating above water and the inside of the hull** do not always receive careful treatment, for here there is no fouling to guard against, but only corrosion, and this may continue for a long period without affecting the vessel's efficiency. For the sake of appearance, the outside of the hull above water is usually covered with paint, but—excepting well-kept vessels—as this often merely serves to hide scale, its efficiency as an anti-corrosive may be very poor. The topside plating is particularly apt to corrode, for the heat of the sun, alternate conditions of wetness and dryness, and the friction of broken water, quickly destroy the watertight and protective qualities of the paint. As regards the interior of the hull, where appearances need not be considered, the coating of the steel work is sometimes much neglected, to paint means an expenditure with no immediate return, and often, therefore, it is delayed until the last coat has disappeared and scale has accumulated. To re-coat efficiently the

[1] *Trans. Institution of Naval Architects*, 1863, p. 162. [2] *Ibid.*, 1860, p. 82.

irregular and more or less inaccessible framework, involves very considerable expense, for unless the old decomposed paint, and rust scale which may have formed below the last coat, are removed, a fresh coat is, of course, of little value.

Art. 463. The steel work within the coal bunkers is particularly liable to corrode; while, in the holds, there may be little evidence of **corrosion, in the bunkers** it is often so pronounced as to call for repairs. There are three causes for this: the difficulty of providing a coating capable of withstanding the abrasive action of the coal; the warm, damp atmosphere of the bunker (warm, because of the contiguous boilers, and damp, because not only is the coal often wet when shipped, but, owing to the warmth, there is much sweating); and the corrosive effect which damp coal (carbon is electro negative to iron) has upon steel or iron. The worst corrosion occurs in the vicinity of the coaling hatchways, for as the coal is shot in from above, it quickly rubs off the protective covering, and rain water may sometimes have access through the hatchways. Throughout the whole bunker, moreover, the coal, by gradually sinking as it is worked out from below, has an abrasive or grinding effect on all exposed parts, laying bare fresh metallic surfaces to the corrosive influences. The parts which suffer the most are the exposed flanges of the reverse frames and bulkhead stiffeners, for they present two surfaces to the coal, and in the case of the reverse frames the inner surface may escape the periodical cleaning and coating. The isolated cross beams and tie bars also suffer severely, for they have, so to speak, to crush their way through the descending mass of coal. The bunker bulkheads, not being structural parts, are generally of thin material, not more than $\frac{5}{16}$-inch, and, in consequence, they are quickly eaten through; in old vessels they are often so much repaired as to be merely a mass of patches. In the case of the 'tween-deck bunkers, the deck plating, especially if it extends over a hot boiler, or boiler room, is often seriously reduced by corrosion, for it is practically never free from coal dust, and drainage water may gather upon it; and, while the sides may be chipped and recoated, the deck seldom is; its thin condition is often disguised by a continuous covering of hard scale, perhaps $\frac{1}{2}$ inch thick. In small vessels, where the bridge house is used as a coal bunker, the side plating, being originally thin, is often seriously reduced by corrosion, it is not uncommon to find it worn through in holes. The best preservative coating for coal bunkers is a bitumastic paint or black varnish; this dries with a hard yet tough, glossy surface, and if properly applied, to **clean** steel, and renewed at sufficiently short intervals, there need be no trouble from corrosion.

Art. 464. Some other parts of the hull which are particularly liable to corrosion may be mentioned here. The tendency of the shell plating to corrode under the sidelights is noticed in Art. 350. When wood work is bolted to exposed plating, sea water, getting between and saturating and perhaps rotting the wood, may cause continuous corrosion; formerly it was customary to fix wood carving on the bow and stern, and, as a result, the plates behind were often eaten through in holes. The upper-deck mast wedges are covered with a coat of painted canvas, and if this should leak, the wedges, becoming saturated with water, may cause unobserved corrosion of the mast plating; as this might be a serious matter, the classification societies require that the masts shall be doubled at this part, and be periodically examined. In some sailing-ships the chain locker is built around the heel of the mast, and in some cases the rubbing action of the cable, and the fact of its being stowed wet and dirty, have caused serious corrosion of the mast. If the upper-deck stringer plate in

the gutter waterway is covered with thin, badly adhering cement, it may suffer from corrosion, due to water lodging below the cement; in some cases the plates have been wasted through in holes. When there is a wood deck, the coaming of the boiler casing and the deck plate or tie to which it connects are specially liable to corrode. In old vessels, the presence of a thick scale of rust on the tie plates may often be observed by a bursting up, or elevated position, of the deck planks covering them (Art. 168).

The **floor plates**, where there is no double bottom, might be expected to suffer badly from corrosion, because they are constantly exposed to damp air and bilge water, and, being covered up by the ceiling planking, are out of sight and inaccessible. In practice, however, this is not found to be the case, for they are periodically coated with cement wash, and although the environment is damp, it is cool. Bilge water is sometimes exceedingly foul, due to the presence of grain, etc., or to drippings from nitrogenous and chemical cargoes, and if allowed to remain it might cause damage to the floors; in the wells of a double bottom, for instance, where foul mud is apt to accumulate and lie for long periods, serious corrosion of the floors, etc., is not uncommon. Corrosion of the floors may be observed by the enlargement of the limber holes, for these are at the lowest part, and, owing to the constant wash through them, they are subject to attrition as well as corrosion. The erosive effect of moving bilge water is particularly pronounced in the case of the thin wash plates or intercostals of the side keelsons; in old vessels they are sometimes wasted entirely away at their lower part. The interior of a double bottom, excepting the portion under the boilers, is usually little affected by corrosion, for as it is cut off from the holds, no corrosive foreign matter has access; the contained air is kept cool by the sea, and the coating of cement wash, if periodically renewed, say, once a year, gives perfect protection.

Art. 465. The **heat from the boilers** is most active in promoting **rapid corrosion of the framework of the hull below.** With shallow, open floors, the reverse frames are the first parts to suffer; in a comparatively short time their upper flanges, if situated near the boilers, may become thin like sheet iron, or entirely disappear, a circumstance disguised by a thick layer of rust scale. The floors and boiler stools also become thin, and may actually waste away in holes, a serious matter in the case of the boiler stools, supporting as they do the heavy mass of the boilers. If there is a double bottom, the deterioration is more rapid; the tank top is generally the first part to suffer, for it is more directly exposed to the heat of the boilers, and its upper surface may be covered with wet, warm coal dust; in many cases it becomes wasted through in holes, sometimes in so short a period as four years.[1] The floors and longitudinals within the tank also suffer, particularly at their upper parts, where most heated; like the tank top they may become thin like sheet iron, or be wasted entirely away in places.

The reason for the **faster corrosion of a double bottom** under the boilers than of open framework, is that here the most favourable conditions for corrosion are always present, namely, *warmth and moisture.* For as the air contained in the tank becomes heated, oven-like, by the hot, top plating, it vapourises the moisture within the tank, and as the resulting moist, warm air is confined, it remains to carry on the corrosion. If the boiler-room tank is in one with the tank under the

[1] An account of some actual cases, and illustrations of the wasted parts will be found in a paper by Mr. A. K. Hamilton, *Trans. Institution of Naval Architects*, 1893.

engine, as is common, the latter may also suffer from corrosion, for, of course, the whole of the contained air is heated, more or less, by the boilers. With open framework there may be the same heating effect, but it is counteracted by the fact that, as the bilges are open to the outer atmosphere, there is a constant circulation of air, so that warm, moisture-laden air may be carried away as soon as formed, and, consequently, the iron or steel does not attain the same high temperature. Leakage of hot water from the boilers is occasionally a source of serious local corrosion; if the scalding water should drop upon a tank top or open framework, it will quickly corrode it away. In small vessels having shallow floors, there may only be an inch or so of clearance between the boiler and the top of the centre keelson, in which case it is not uncommon to find the upper angles and covering plate wasted thin, and completely gone under the seams of the boiler shell, where there may have been leakage.

To repair wasted framework under the boilers properly is exceedingly awkward, owing to the general confinement and inaccessibility. As a rule the expense of temporarily removing the boilers is avoided, the work of repair being carried out in a sort of piece-meal fashion, a little bit at a time; in many cases, instead of renewing thin parts, they are doubled, and often not in a very satisfactory manner. In some cases, to avoid expensive repairs, it is preferred to abandon the tank as a receptacle for water ballast, and merely strengthen the wasted framework sufficiently to maintain the general strength of the hull. In exceptional cases the simple plan has been adopted of filling the tank quite full of cement concrete, the solid mass of which, with the embedded floors and longitudinals, though weighty and clumsy, forming, as regards rigidity, a very capable substitute for the original floors. But, of course, though giving perfect stiffness and support to the shell, a mass of concrete can confer little or no strength against tensile stresses. It should be observed that the shell plating and attached frame angles do not suffer at all from corrosion, for they are embedded in cement, and are kept cool by the contiguous sea water, a circumstance which permits of extensive repairs being done afloat.

To provide a margin of strength against rapid corrosion, the bottom framework under the boilers is made of extra thickness (Art. 185), and in some cases iron is substituted for steel. An increase in thickness does not retard corrosion. To accomplish this the main requirement is **to prevent the warming of the tank top and internal framework**, for, of course, in the absence of heat, there would be no more corrosion here than elsewhere. This desirable result may be secured, in great measure, by placing the boilers well up above the floors or tank top, and leaving the space between as open as possible, so as to permit of a free circulation of air. The rate of corrosion diminishes very rapidly as the height of the boilers is increased, for not only is the heating effect more feeble, but the space below, being less confined, admits of a quicker and more thorough removal of the heated air. The usual clearance between the tank top and the boilers is from 12 to 18 inches; to increase it to 24 inches would be very desirable, but, unfortunately, the occurrence of deck beams above does not always permit of this. An obvious method of preventing heating of a boiler-room tank is to keep it always full of water; but this is equivalent to carrying permanent ballast, which, in a properly designed cargo vessel, would, of course, be undesirable. The upper surface of the tank top is usually protected from corrosion by a watertight coating, either of Portland cement, tar and cement, bitumastic cement, or black varnish. Bitumastic cement—of a kind which does not soften too much when warm—when laid on about 1 inch thick, forms an excellent

covering, but, while protecting the upper surface of the plating, neither it nor any other thin coating prevents the passage of heat and consequent corrosion within the tank. This result is sometimes attained to a considerable extent by covering the tank top with a layer of cement 3 or 4 inches thick, or with a flooring of bricks embedded in cement, for, by its insulating or non-conducting properties, such covering prevents the free passage of heat. When laid on a large, smooth, plated surface, thin cement does not adhere; it may crack, rise from the plating, admit water below and result in unobserved and perhaps serious corrosion of the plating. This may be avoided by riveting angle or jackstay bars on the tank top, about 2 feet apart, for these have the effect of locking the cement, so that it adheres as a solid mass to the plating.

The upper part of the boiler is lagged (*i.e.* it is covered with thick non-conducting material, termed "lagging"), and if the bottom were also lagged, comparatively little heat would pass out to the tank top. To lag the bottom of a boiler requires special arrangements, but since the recent introduction of suitable lagging material, it is now occasionally done, and with excellent results in checking corrosion. If, in conjunction with bottom lagging, baffle plates were introduced between the boilers and the tank top, so as to intercept radiant heat, if the tank top were thickly coated with cement, and air were allowed free access, there would be little trouble from corrosion. It is sometimes attempted to ventilate the inside of the tank, so as to carry away heated air, but with the usual small openings a sufficient circulation of air can only be secured by mechanical means.

The framework within the boiler-room tank is usually coated—as in other tanks—with cement wash, but in some cases double-boiled linseed oil is used with good results; to be effective, however, such internal coatings require frequent renewal; in some cases they are found to last so short a time and to give protection so poor, that it is not thought worth while to apply any coating at all. As noticed in Art. 195, some shipowners have experienced so much trouble and expense from the corrosion of boiler-room tanks that they prefer not to have them in their newer vessels; this is to be regretted, for to abandon a continuous inner bottom, with its great structural efficiency and the safety which it confers to the ship, is undoubtedly a retrograde step.

Art. 466. A curious phase of **corrosion** is its **bursting effect on riveted work.** Should the rivets binding two parts together be wide apart, water getting between and setting up corrosion results in the formation of rust scale, which, becoming thicker and thicker, may force the parts asunder, bending them in loops between the rivets, and ultimately breaking the latter. Figs. 22 and 23, Plate 50, represent a frame angle of an old vessel so affected—the black portion represents the scale. It is a feature of such corrosion that it only affects joints in which the rivets are wide apart in relation to the thickness of the parts connected; while one in which the rivet pitch is over, say, 9 diameters, may corrode badly, another, having a closer pitch, though subject to the same conditions, may not suffer at all. In both joints water may have access between the faying surfaces, but while in the one the only effect is the formation of a thin, cement-like scale, which merely fills and tightens the joint, in the other the scale gradually increases in thickness, and ultimately bursts the parts asunder. The continued growth of the scale in the latter is due to the smaller clamping effect of the widely spaced rivets; and the immense bursting pressure which, when it has become thick, it appears to acquire (while the thin scale in the closely riveted joint appears to have none) is probably due to an increase in its bulk through chemical change.

These effects are, of course, only observed in vessels of considerable age. In those of modern build it does not occur so readily, for the spacing of the rivets throughout the structure is closer than that formerly adopted. In old vessels, for instance, the spacing of the frame, beam, and keelson rivets often exceeded 9 diameters, but now the maximum is 7. The presence of thick scale between the shell plating and the frames is, of course, a serious matter, for the condition of the rivet shanks is then doubtful; they may be wasted away or perhaps be broken; and should any straining occur, the brittle scale might fall out and leave the rivets loose, which, if below water, would result in dangerous leakage. The presence of scale between the frames and the thin side plating of a poop, bridge, or forecastle may be observed in almost any old vessel; if examined merely from the quay side, some of the frame rivet points may usually be discerned, each one in the centre of a slight depression in the plating (somewhat like the buttons in a cushion), and some may have drawn partly through the plating. Extensive repairs have often to be made on this account, the shell rivets being cut out, the scale removed, the holes recountersunk and re-riveted; in some cases the frames, and the plating behind them, may be so much wasted as to require renewal. The riveted seams of the fiddley casing are particularly liable to suffer from accumulations of scale between the faying surfaces; it may be observed here in comparatively new vessels, and is due to the thinness of the casing plates, a wide rivet pitch, the heat from the funnel, and exposure to sea water. To avoid it, the rivets should be closely pitched, not more than $4\frac{1}{2}$ diameters, and the entrance of water should be prevented by caulking the exposed edges.

Art. 467. One of the principal causes of internal corrosion is the **sweating** of the steel work, *i.e.* the condensation of the moisture in the air within the holds. This is brought about in the same way as ordinary dew, or as the moisture which forms on a glass of cold water in a warm room. Warm air can hold in suspension much invisible water vapour, but should such moisture-laden air be chilled, then, being no longer capable of holding so much moisture, the surplus would be deposited as dew or sweat. Through the day, the deck and side plating are warmed by the sun, and, in turn, warm the air within the hold, so that it may vaporize and hold in suspense much water; but at night, these parts again become cold, and, by chilling the contiguous air in the hold, cause it to deposit upon them its surplus moisture. On examining the inside of a ship which has just returned from a long voyage, evidence of sweating may be clearly observed by rusty streaks and stains where the moisture has lain or trickled down—signs which may readily be mistaken for evidence of leakiness. Excessive sweating may cause damage to cargo; to avoid it, **delicate goods are carefully dunnaged** to keep them clear of the steel work, and cargoes such as grain or flour are further protected by matting and canvas coverings.

When the upper deck is of wood, or of plating sheathed with wood, there is much less sweating, for as the wood planking forms a thick non-conducting layer it does not readily transmit heat or cold, and as the air within the hold remains at a more even temperature it does not alternately vaporize and condense so much moisture. For this reason, in passenger vessels, and those which carry fruit or cargoes particularly susceptible to damage by moisture, it is essential that the upper deck should be of wood, or be wood sheathed. If cabins are placed immediately below a plated upper deck, and are not covered on the under side with wood lining or panelling, the sweat, dropping on the furniture, sleeping berths, etc., is, of course, very objectionable. To avoid it, it is common to coat the plating

forming the roof of the cabin with **granulated cork**; first a coat of sticky varnish is applied, then the cork is dusted thickly over it, and the whole finally painted with two or three coats of white paint. This covering is so good a non-conductor that even should the deck become cold it will not at once chill the contiguous air of the cabin. The Board of Trade requires, in the interests of seamen, that exposed deck plating over their sleeping berths shall be lined with wood, for, unlike cork paint, the efficiency of a wood covering, as a protection against sweating, is never open to doubt.

Art. 468. Of **anti-corrosive coatings** there are five distinct kinds: oil paints; spirit varnishes; tar, tarry compounds or asphalts; Portland cement; and galvanizing. An oil paint differs from a varnish in that whereas it dries by oxidation and increases in bulk, a varnish dries by evaporation and diminishes in bulk. A paint consists of two parts, the *vehicle* and the *pigment*. Linseed oil is the usual vehicle, in drying it oxidizes and forms a tough, leathery skin, termed "lenoxin." If used alone it would be too thin and porous; to give it, therefore, the necessary body or substance, a pigment is added—usually a mineral oxide. Although it then forms a tough elastic covering, it is neither perfectly air nor water-tight, for it contains minute pores, which enlarge as the paint ages; to provide, therefore, a durable and watertight surface of paint, two or more coats must be applied, so that each may fill or cover the pores or fissures in the one below.

There are several **pigments** in general use. Redlead or oxide of lead, whitelead or carbonate of lead, red oxide or oxide of iron, oxide of zinc, metallic zinc in a finely divided powder, and lamp black. Although all of these give good results, the metallic zinc has the advantage that a paint made with it is, under all conditions, perfectly harmless to the steel. So long as a paint remains sound and impervious to water, the pigment, being wrapped up in it, can have no effect on the steel; when, however, it decomposes and becomes dry and flowery, the pigment, being thrown into direct metallic contact with the steel, may, if electro-negative, exercise a corrosive effect. Now, whereas lead and oxide of iron are electro-negative to iron, zinc is electro-positive, so that should a zinc paint decompose, the resulting contact of the pigment with the steel would actually retard corrosion. In practice, however, good redlead (the quality of paints varies very much) is rarely found to have any prejudicial effect on steel; it has had, and still has, a more extensive use than any other paint, for it has excellent adhesive and covering qualities, and its endurance is often remarkable. It is almost universally used for ships' bottoms, for the first and second coats; and alone for inside work.

In applying oil paint, it is essential that **the steel should be perfectly dry,** for if not its adhesion may be very imperfect; paint which has been applied to wet plates may sometimes be torn off in ribbons. If the steel is warm when painted, the adhesive and enduring qualities of the paint are greatly enhanced; in evidence of this, cases are sometimes cited of finding, when breaking up old iron structures, the manufacturers numbers which were painted on the hot plates with whitelead at the iron works. Advantage is sometimes taken of this circumstance in the case of the masts and yards; when once riveted up, the interior of an ordinary spar cannot be recoated, but if, as is common, each plate is painted while still hot, after rolling, recoating is unnecessary.

The **varnishes** used for ships' bottoms contain, instead of oil, a volatile spirit, such as naphtha, benzine, turpentine, or bisulphide of carbon, in which resins or gums are dissolved, and, in addition, to give colour and body, a pigment, usually red oxide. These spirit varnishes are distinguished by

their quick-drying properties, and are, therefore, extensively used when dispatch in dry dock is necessary. They are applied only as an outer, anti-fouling coating, that next the shell plating being an oil paint—usually redlead. If too volatile and quick-drying they do not form a very efficient coating, for their rapid evaporation chills both the steel and the contiguous air, in consequence of which, if the latter is humid, its moisture may be deposited on the varnish as dew, with the familiar result of precipitating the gums as a non-coherent powder, and destroying the elasticity and impervious qualities of the coating; and, moreover, in drying quickly, a varnish may contract and crack. Oil paints, being slow in drying, have little chilling effect, so that if the plating itself is dry, humidity of the atmosphere, although retarding the drying, is not prejudicial.

Pure **coal tar** forms **a good anti-corrosive** covering, for it is perfectly impervious to water, and, when applying it, it adheres with persistence whether the plating be wet or dry. In its raw state coal tar is objectionable, for it may contain impurities prejudicial to the steel—ammonia salts, and acids. It is rarely used for coating ships' bottoms, for it is dirty and does not dry. If long boiled, it hardens into a brittle pitch. If applied to hot plates, it forms a tough and durable coating. It is often **used for tank tops**, and sometimes for deck plating, in which cases it is laid on thickly and then besprinkled **with Portland cement**; the latter, being absorbed by the sticky tar, converts it into a thick, tough, asphalt-like layer, perfectly adherent and impervious to water. In better-class work, Stockholm tar is substituted for coal tar, cement being used as before. Sometimes black varnish is used, but a tar and cement coating is generally preferred, because, forming a thick layer, it affords better and more enduring protection to the plating.

The **black varnishes** commonly used are bituminous or asphaltic compounds, prepared usually from the residue of mineral oils. They resemble tar in many respects, for they are perfectly impervious to water, and may be applied to wet plates; they are of a waxy nature, and dry with a tough glossy surface. They are very suitable, and are much used, for coating the interiors of coal bunkers, and for the outside of the shell plating of coasting vessels. In warships they are employed as a substitute for Portland cement, for the bottom inside.

Art. 469. The **fouling** of iron and steel ships is a constant source of trouble; if the bottom of a sailing-ship is very foul, she may take 50 per cent. longer on a voyage, and in a steamer the speed may be reduced by several knots, causing, of course, a large additional expenditure of coal. Ever since the introduction of iron ships there has been a sustained yet unavailing endeavour to produce a perfect **anti-fouling paint**, *i.e.* a composition which, like the copper on a wood ship, is proof against the attachment of sea-weed and barnacles. Many hundreds of methods of avoiding foulings have been tried, patented or proposed (even before 1870 two hundred patents were taken out), but a perfect one has not yet been invented. Numerous patent anti-fouling compositions are available, but all that can be said of them is that they are more or less successful in retarding or delaying fouling, and, indeed, this is all that is really claimed or expected of them. The anti-fouling properties are secured by the introduction of certain poisonous matters, such as copper or arsenic, and by giving to the vehicle a certain soapiness of consistency, so that, by washing away slowly, the poisonous matters, otherwise wrapped up and innocuous, may be laid bare. It is evident that a vessel's bottom, when coated with such a composition, must present a very uncongenial habitat for germs of marine life, for those seeking to attach themselves, if not at once washed off, would

probably be poisoned before they obtained a secure hold. It should be observed that when marine growths once secure an attachment, the poisonous nature of the paint has little effect upon them, for the attaching medium is not, like the roots of a plant, a means of nutrition, but acts merely as a mooring. While a vessel, when newly painted, is lying in harbour, the contiguous layer of still water may be rendered so highly poisonous as to turn off or destroy any germs essaying to attach themselves; but, when at sea, any poison that exudes from the paint is so diluted by the limitless volume of pure water passing over the surface, that its deleterious effect becomes inappreciable.

The success of an anti-fouling paint depends very largely on the vessel's movements after coating, the time she lies in harbour, the length of the voyage, the particular seas navigated (whether warm, tropical seas, teeming with active germ life, or comparatively cool seas such as the Atlantic), the season of the year, and other matters. For vessels in a regular trade and route, a composition is usually found well suited to their requirements, but the same one might be quite useless in another vessel differently engaged, for it might wash off too quickly, or too slowly, or it might be insufficiently poisonous, or its anti-fouling qualities might not be fully developed at the right time. Mail boats and others, making voyages to the East or to the Cape, are recoated, as a rule, each time they come home, *i.e.* every three or four months, but at certain seasons, when germ life is less active, the same composition may serve for two voyages. American liners, navigating the cold Atlantic, need only be coated once a year.

For sailing-ships, making long voyages, one of the oldest, and perhaps one of the best, anti-fouling coatings is tallow melted down and applied hot, a little white zinc or red oxide being added to give body and colour; it has the advantage, not possessed by many other anti-fouling compositions, of being also a very perfect anti-corrosive. Among other odd compositions, common, powdered blacklead, mixed with sour beer or water acidified with vinegar, is sometimes found to give excellent results. Of course, anti-fouling compositions are only applied as an outer coat, on the top of redlead or other anti-corrosive paints; to apply some of them to bare plating might give very poor results, for having as a single coat little or no anti-corrosive qualities, they would be quickly thrown off by corrosion of the plating below. At each dry docking the bottom receives only one coat of anti-fouling composition, the one last applied having disappeared or lost its anti-fouling properties, and, of course, before coating, the weed, shells, and loose paint are scraped off more or less thoroughly. As regards the preservation of the plating, it is well sometimes to chip off all the old paint and recoat the bare iron with anti-corrosive paint, for after many years paint loses its properties as a protective watertight covering; in old vessels it is common to find a hard scale of oxide below the paint. When several coats are applied, one after the other, they should be differently tinted, so that, as each fresh one is put on, no part may be omitted.

Art. 470. Wood ships, owing to their **copper sheathing**, enjoy perfect immunity from fouling. The copper sheathing not only prevents fouling, but protects the planks from the attacks of worms; in the latter respect it is essential in all vessels navigating warm waters. Marine growths cannot attach themselves to copper, for the reason that its surface is under a constant process of conversion into soluble, poisonous salts of copper, which, in washing off (or "exfoliating," as it is sometimes, not very aptly, termed), carry away any germs which may find a momentary fixture. A copper-sheathed ship may remain afloat, without docking, as long as the sheathing

lasts, *i.e.* four years or more, according to its original thickness. At one time pure copper was used, but latterly yellow metal was substituted, for, while possessing almost as good anti-fouling properties, it lasts longer and is cheaper. With a view to still greater economy, **zinc sheathing** has been tried on wood vessels, but, though giving protection against worms, it has no anti-fouling properties.

Steel warships are commonly sheathed with copper, the under-water hull being first sheathed with wood to prevent metallic contact between the two metals, for, of course, if sea water penetrated freely to the steel shell, and if this and the copper were anywhere in contact, they would form a powerful electric battery, to the rapid destruction of the wetted steel. Zinc, being electro-positive to iron, might be fixed as a sheathing directly to the shell plating, and, by itself wasting away, protect the steel and at the same time prevent the attachment of marine growths. Apart, however, from the difficulty of attaching the zinc, it was found, in cases in which it was tried, that it wasted too rapidly, through excessive galvanic action; and that where it did not waste thus rapidly, it did not prevent fouling. As noticed later, small vessels are galvanized with zinc, but this is a different thing from zinc sheathing.

Between the years 1860 and 1870, before the opening of the Suez Canal, when the China tea trade was conducted with large sailing-ships (steamers could not then be profitably employed on the long voyage round the Cape), a quick run home was so important that the cleanness of bottom due to copper sheathing was thought essential. To revert to small wood ships was, of course, out of the question, and to sheath iron ships with wood, with a view to coppering them, was deemed too costly. Accordingly, the well-known **composite system of shipbuilding** was introduced, in which the hull is built of iron, with the exception of the shell, which is of teak wood, from 5 to 6 inches thick. Not many vessels were constructed on this plan, for, with the opening of the Suez Canal, steamers took up the tea trade; and although, in the matter of strength and durability, those built have proved satisfactory, the advantage of immunity from fouling is an insufficient offset to their great costliness. For this and other reasons the composite system of construction is, as regards merchant vessels, practically obsolete; for yachts, however, it is particularly suitable, and is frequently employed.

In **warships** it is very necessary that the bottom should always be clean, for on this depends two of their essential qualities—speed and small coal consumption. Accordingly, those which are likely to be engaged in distant cruising are always **wood sheathed and coppered.**[1] The present practice of the British Admiralty is to build the hull of steel throughout, in the usual way and of the usual scantlings, and finally to fit teak planking about $3\frac{1}{2}$ inches thick on the under-water shell. At one time, in order to insulate thoroughly the copper sheathing from the steel, it was thought necessary to fit two thicknesses of planking (Fig. 2, Plate 35). The planks are fastened by *naval brass bolts* (Art. 577), inserted from the outside and screwed right through the plating, so that nuts may be hove up on their points within, as a security against stripping of the thread in the thin shell plating. Their heads are sunk well below the surface of the wood and are covered with marine glue, so that they may not form points of contact between the shell plating and the copper. Before the planking is fitted the watertightness of the shell plating is tested by hose, and the bolt holes are drilled in the shell after the planking is fitted. To avoid galvanic

[1] Valuable information on the subject of sheathing will be found in Sir W. H. White's paper in the *Trans. Institution of Naval Architects* for 1895.

action it is essential that no water shall pass through to the shell plating, and so, not only is this thickly painted and the wood sheathing carefully caulked, but redlead is injected between the planking and the plating, so that, by filling every crevice, water may neither find access nor lodgment. Every part of the under-water hull is covered with wood except the stem, stern-frame, rudder, and shaft-brackets, and as these, therefore, cannot be of steel, they are of phosphor bronze (Art. 577). As the shell plating receives considerable stiffness and support from the planks, a reduction in its thickness might be thought admissible; but in large vessels the thickness of the plating is regulated by the requirements of longitudinal strength, towards which wood planks can contribute little assistance, and in small vessels, where it may be dependent on the requirements of local stiffness, a reduction is usually undesirable, for, among other reasons, if the plating were thinner than $\frac{5}{16}$ inch (a common thickness in small warships), the sheathing bolts, tapped through it, would have but a poor grip.

Art. 471. Galvanizing is largely employed for protecting small deck fittings from rusting, for rails, awning stanchions, bollards, fairleads, ventilators, deck bolts, cleats, etc. These are well suited for galvanizing, for they are small, and, being completely finished before treatment, there is little chance of the zinc coating being broken of by subsequent hammering. It is also employed for the structural parts of small vessels, whose slender scantlings afford little or no margin against corrosion. Torpedo boats and small craft for tropical rivers and lakes are always galvanized, each plate and bar being separately treated in the galvanizing bath after it is shaped and punched ready for fitting in place in the hull. In high-class yachts the deck beams and deck plating are usually galvanized, with a view to avoiding rusty discoloration of the cabin roof, such as might occur through deck leakage or sweating.

A thin skin of zinc, if it were complete and continuous, would afford very perfect protection to the under-water **shell plating**, but as the riveting is done after the galvanizing, not only are the rivet points exposed, but the hammering may chip off the surrounding zinc, with the result that the exposed steel, by forming a galvanic couple with the zinc, may cause its rapid corrosion and disappearance. Even apart from galvanic action, zinc itself, when exposed to sea water, corrodes and wastes away rapidly by oxidation. For these reasons galvanized hulls and deck fittings are painted in the usual way. The galvanizing is useful, nevertheless, in affording additional protection, an important matter in small boats whose shell plating may not be thicker than $\frac{1}{8}$ inch. It is particularly suitable for **river and lake boats**, the bottom painting of which may often be scrubbed off, for fresh water, unlike salt, does not corrode zinc, and has little galvanic effect. Fresh water is also very inert as regards ordinary corrosion; the fresh-water lake steamers of North America, for instance, suffer little from external corrosion, even though the shell may be imperfectly covered with paint. Paint adheres badly to a smooth, galvanized surface, but this may be overcome by artificially roughening the zinc, by treatment with some corrosive fluid.[1]

Until recently all articles were galvanized by immersing them in a bath of molten zinc. For slender parts, such as shell plates and frames, this is not satisfactory, because the high temperature causes them to warp. Lately, however, an electric process has come into use, in which a cold solution of sulphate of zinc takes the place of the hot molten zinc, a suitable electric current causing the required deposition of the metal. By

[1] See Mr. P. Wood's paper, "*Rustless coatings for iron and steel*," *Trans. American Society of Mechanical Engineers*, 1894.

this process the work is done rapidly and economically, and with no distortion of the articles.[1]

Art. 472. Portland cement is extensively used in the shipyard; as a wash, it forms a substitute for paint; and as a thick layer or paying, it protects the bottom plating from attrition as well as from corrosion. **As a wash**, it is mixed with water to the consistency of thin gruel and applied with brushes. It is used thus for coating the floor plates, etc., in the bilges below the ceiling planking, and for the interiors of double bottoms. Owing to the damp and foul surroundings of the bilge, oil paint would be difficult to apply, and would not long endure, whereas cement-wash may be applied to wet plates, which it is not essential to clean thoroughly or scale; its cost is trifling, it may be put on expeditiously by labourers, and it will harden although immersed in water. For the interiors of double bottoms oil paint is inadmissible, because, apart from the damp surroundings, the fumes from the paint would asphyxiate the men; Portland cement, on the other hand, purifies the air, for it has valuable antiseptic properties, so much so that it is sometimes used as a substitute for lime, for coating the interior of drinking-water tanks. Cement wash is also very commonly used for the lower part of the peaks, but unless the air here is damp and foul, it is not better, and is much less durable, than a good coat of oil paint. Unlike paint, it is not impervious to water; nevertheless, as it is alkaline, it has a markedly deterrent effect on corrosion (iron will not rust in lime water); in time, however, it loses this property, and requires, therefore, to be frequently renewed. It is usually applied in a single coat, but a double one gives better and more enduring protection.

The most important application of **Portland cement** is its use **as a protective layer or paving** on the inside of the bottom plating, for which purpose it is mixed with sand, as a mortar. When thus applied it not only protects the plating against the corrosive effect of foul bilge water, but against the erosive action of any hard substance which may wash about with it. Sand and stones from ballast, bolts, rivets, etc., often gain access to the limbers, through chinks in the ceiling planking or when planks are carelessly lifted during inspection, and as they are washed with the rolling of the ship continuously from side to side, the continued erosive effect, for months together, soon wears away the cement. Loose sand or gravel wears it in patches, and lays bare the rivet heads, which, in time, may also be worn away flush with the plating. A loose stone or bolt cuts a furrow in the cement, often right through, and into the plating, and many cases are on record where plating has actually been perforated by the long-continued wearing action of a stray bolt. It is evident, therefore, that a thick covering of hard cement is very necessary for the preservation of the shell plating and the safety of the ship, and also that it should be frequently examined and renewed where worn. The cement in a double bottom is not often exposed to serious wearing action, for no solid objects find access to the tanks, unless it be a bolt or rivet carelessly left by workmen during repairs; and in view of this it is sometimes dispensed with, but the tanks in such cases must be inspected at frequent intervals. In oil vessels the bottom shell plating is not usually cemented; it is sometimes, however, for, as already noticed, it is found to be subject to peculiar corrosive effects, the inner surface of the plating, close to the landing edges, becoming furrowed out in a surprising way; this may occur, of course, when the oil tanks are used for cargo or water ballast. Sugar has a very corrosive effect on iron. At one time, when it was shipped in an unrefined state, the molasses, leaking into the bilge water, caused serious corrosion of

[1] Cowper Cole's process. See *Engineering*, October 6, 1899.

the floors; some of the earlier vessels were not cemented, and a case is on record where shell plating $\frac{1}{2}$ inch thick was eaten through in six months' time.[1] To provide against the action of sugar the cement was sometimes worked up the floors, and this is also done in vessels which carry copper ore, for copper in solution in the bilge water has a very corrosive effect on the iron work. The permanence and durability of Portland cement is not readily affected by ordinary substances; sulphate of ammonia, however, is an exception, it makes it quite soft, and as it is largely exported from this country, its injurious effect should be kept in view.

In the earlier iron vessels the cement was laid very thick, 3 or 4 inches at least, so that it might be level with the limber holes in the floors, and it was usually mixed with broken bricks to form a concrete. In some fine-lined ships it was laid about halfway up the floors so that it might serve as permanent ballast. **Yachts** require ballast to immerse them to their designed water line, for they carry no cargo, and must be of fairly full form below water in order to secure sufficient breadth and area in the cabin floor. In steel yachts **cement concrete** is generally used for this purpose, in addition to portable iron or lead ballast; and sometimes cast-iron blocks or scrap iron are imbedded in the cement. The concrete amidships is usually laid so deep as entirely to cover the floors; this is an excellent arrangement as regards the durability of the structure, for steel or iron when buried in cement is practically everlasting. The bottoms of wood vessels are not cemented, for the ceiling planks are here so thick and well fitted that there is little chance of anything passing below; nevertheless, a stray stone has been known to cut a dangerously deep furrow in the outer planking. The bottoms of composite vessels are cemented to protect the planks, frames, keel plates, and numerous bolt heads.

In modern vessels, to reduce weight, the cement on the bottom is usually thin—little more than 1 inch; it is worked up as a fillet over the frame rivets, and special drain holes provided, as described in Art. 90. It is usually laid rather thicker towards the keel, where the greatest attrition may occur, and is tapered off towards the bilge; but, as noticed later, it should not be thinner at any part than at least 1 inch. In laying it, it is endeavoured so to work it that at no place may bilge water be trapped or locked up, but tend everywhere to run down to the keel and thence pass fore-and-aft through the drain holes. The "pockets" between the deep floors at the bow and stern (Fig. 12, Plate 29, and Plate 110) are always filled more or less deeply with **cement concrete**, limber holes being provided at the proper height to drain off water; if these confined and inaccessible spaces were not filled with cement, dirt would accumulate and cause continuous and unobserved corrosion. When cement is as thick as 3 inches, it is mixed with broken bricks or coke, for the resulting concrete is cheaper and no less efficient. A coke concrete has the advantage of lightness, but the coke should be hard and clean, and the cement so well mixed with it as to fill all interstices. Sometimes, for the sake of economy, furnace refuse, composed of ashes and small cinders, is substituted for coke, but this does not make a good, solid concrete.

Art. 473. Cement has **other applications**; it is used as a protective paving for the stringer plate in gutter waterways, and for the deck plating in the galley and donkey-boiler house; in the latter places it is particularly useful, for it is unaffected by dirt, heat, and moisture. In passenger vessels the deck plating in the water-closets, lavatories, and bath-rooms is cemented and tiled; and when there are several water-closets or bathrooms in a group, the wood coamings of the partitions should be

[1] Martell, *Trans. Institution of Naval Architects*, 1880.

elevated above the tiles (by fixing them to deep angle or Z lugs riveted to the plating), so as to keep them clear of water and permit of the floor being washed by hose in one operation, and of being drained by one scupper (see Fig. 2, Plate 73). It is also used for filling the trough-like spaces between the frames at the sides of the 'tween decks and at the upper margin of the ceiling planking at the bilge; as a substitute for wooden wedges at the heels of the masts, and for the deck plank next the hot machinery casing. It is also sometimes employed under the winches and steam pipes of deck machinery.

In **steamers which carry cattle**, to provide a good foothold, the deck plating under the stalls is sometimes paved with cement, and, further, to prevent the animals from slipping and falling in heavy weather, ledges of wood—*foot-locks*—are provided, being fixed, clear of the cement, to projecting lugs tap bolted or riveted to the deck plating. This cement covering affords little protection to the plating, for, as it seldom exceeds 1 inch in thickness, it does not adhere, and as it has no marginal angle and may become cracked in places, water and urine from the cattle are free to collect below, with the risk of unobserved and serious corrosion of the plating. For these reasons, it is now common to substitute a thick coating of bitumastic cement or asphalt. In vessels adapted for the cattle trade, and whose decks may be of wood, the necessary protection from wear and tear is secured by doubling the deck under the cattle stalls.

Art. 474. Portland **cement is composed of chalk and clay** (lime, silica and aluminium) ground down with water into a dough, calcined in a kiln, and then ground into the familiar blue-grey, flowery powder. When mixed or *gauged* with water into a dough, it undergoes, in a few minutes, a chemical and molecular change, it stiffens, and is said to *set*. Some cements may set in ten minutes or less from the moment of mixing with water, others may take much longer—half an hour or more; the former would be described as "**quick-setting**," the latter as "**slow-setting**." This set does not leave the cement hard, it merely transforms it from a soft, wet dough into a comparatively dry solid; its surface, formerly glossy with water, becomes dry, and, to work it further, more water must be added. The actual *hardening* of the cement, after it has set, is gradual; it may be said to be hard when the thumb nail cannot indent it. A quick-setting cement may harden within an hour, a slow-setting one in from two to six hours; this hardening is sometimes referred to as the second or final set. A distinctive characteristic of Portland cement is that it hardens just as well under water, fresh or salt, but it takes about four times as long. It is, therefore, termed a "hydraulic cement." Cement should not be worked or moulded after the period required for the initial set, for it has then "crystallized," and to disturb it would prejudice its subsequent efficiency as a hard, coherent, and adhesive mass. For ship work, where a considerable period may elapse before the gauged cement is finally laid in place, a slow-setting one should be employed. Freshly made cement is usually too quick-setting; if kept for some months it improves, becoming slower-setting, and more suitable for general purposes.

Cement may be fine or coarse-ground. Its fineness is tested by sifting a sample through a hair sieve and noting what percentage does not pass. With an ordinary cement all but 5 to 10 per cent. will pass through a sieve having 50 meshes to the lineal inch (or 2500 per square inch), and an exceedingly fine one will all pass through a sieve having 180 meshes to the lineal inch. The finer the cement the stronger is its agglutinating power when mixed with sand in the usual way; if used neat, however, *i.e.* without sand, it will be less strong than a coarser one. There are two

essentials in good cement: when set hard it must be strong, and during the setting and hardening it must not shrink and alter shape, or "blow," as it is termed. The principal test to which cement is subjected is a **tensile** one, briquettes of neat cement, 1 square inch in section, being formed in moulds and drawn asunder in a testing machine. The **strength** increases with the age of the briquette; seven days is the period usually allowed, during the last six of which it is immersed in water. The strength of a seven-days briquette varies from 450 to 500 pounds per square inch, the standard commonly specified being 350 pounds. If a briquette is kept for a month it may become 25 per cent. stronger; a slow-setting cement, although less strong at the end of a week than a quick-setting one, will gain more strength through time, and, ultimately, will usually be the stronger. The above refers to neat cement, in which condition the tests are usually made. When mixed with sand in the common proportion of three of sand to one of cement, the tensile strength will be considerably less—with ordinary cements little more than one-third, but with finely ground ones about four-fifths.

Any **tendency to blow**, *i.e.* to alter shape during the hardening, is a fatal fault; a cement that does so is unfit to be used. It occurs usually in those which contain too much lime. A good test for this defect is to place a small, neatly moulded briquette on a piece of glass, allow it to set hard in a moist, warm atmosphere (100 degrees Fahr.), and then immerse it for twenty-four hours in warm water (110 degrees Fahr.); if it is then found to be quite hard and adhering to the glass, it is good, but if deformation has occurred, or if it has parted from the glass, it is bad and unfit for use.[1]

The **proportion of sand and cement** adopted in ship work varies greatly; in some shipyards equal parts are used, in others three of sand to one of cement. The less sand the stronger the finished mass, but as a high degree of strength is not essential in a mere paving, the precise proportion, whether three-to-one or less, is unimportant, so long, of course, as both are of good quality, and are well mixed and properly applied. When laid thick, say over $1\frac{1}{2}$ inch, a three-to-one proportion may be perfectly efficient; if thinner, a two-to-one, or equal parts, is preferable, for the cement is then stronger, it adheres better, and is less pervious to water. The mixing is often done very carelessly, the sand and cement being measured in a rough and ready fashion by shovelfuls, and, as a result, some parts of the cement on the vessel's bottom may have so much sand as not to attain sufficient hardness and strength. The sand should be free from loamy matter, and it should be sharp, *i.e.* the particles should not be round, but jagged; quartz sand is, therefore, the best. Formerly, importance was attached to the employment of fresh-water sand, for it was thought that the salt in sea sand prejudiced the hardness and durability of the cement; the presence of salt, however, merely retards the setting; cement that is gauged with sea water takes about four times as long to set, but its ultimate hardness is little affected.

Art. 475. Cement will adhere to any clean surface. A briquette one inch square, placed on a sheet of glass, was found, after a year, to have an adhesive force of 125 pounds; the adhesion to an iron plate, after a month, was 68 pounds.[2] Adhesion so perfect is rarely found in the cement on a ship's bottom; the cement in each frame space is firm and immovable, but its fixture appears to be due chiefly to the "dovetailing" of its margin, where it covers the frame rivets; if broken away carefully, with a view to leaving an isolated patch on the smooth plating,

[1] See *Engineering*, September 22, 1893.
[2] See *Trans. Institution of Civil Engineers*, vol. lxxi., p. 267.

the whole will usually loosen prematurely, displaying little adhesion. But although there may be no actual adhesion, the cement, nevertheless, fills so perfectly every crevice and pore of the iron work, that it really forms a perfectly watertight sheathing; after many years, when thick cement is removed, the original smooth bloom may usually be observed on the plates. At one time it was common to paint the plating before laying the cement, and although cement does not adhere at all to an oily surface, still, when broken away, the paint may be found as fresh as when first applied, showing that, despite the absence of adhesion, the cement formed a perfectly watertight covering. The absence of adhesion is particularly noticeable when the cement covers an extensive plated area, such as a deck or tank top. When broken away it may be found to be not even in contact with the plating, in which case, of course, it can have little value as a protective covering, for should it be thin and crack, or should it have no boundary bar, water is free to pass below it. To cover a large area of plating with an enduring layer of cement, small angle or jackstay bars should be riveted to the plating about 2 feet apart, and the cement laid over all. Even in the narrow zones between the vessel's floors, if the cement is thin, say less than 1 inch, the clamping effect which it receives at its margin may be insufficient to prevent it from parting from the plating between them. Even then no harm may result so long as water does not enter; often, however, it does enter, in way of buttstraps, for instance, where the strap may not entirely cover a badly fitted butt, and especially at the marginal part of the cement at the bilge, where want of contact means a crevice, open to receive the sweat which trickles down the vessel's side.

Art. 476. The **solidity of the cement** on a vessel's bottom is **tested** by striking it with a bar or hammer; if hard and in contact with the plating it emits a solid ring; if soft, or if it has risen from the plating, it sounds dead or hollow. Cement is not impervious to water, it absorbs it; if thick and adhering to the iron, however, whatever absorption there may be does not cause any corrosion of the iron; if thin, rust scale may form below. On breaking away thin cement, it is common to find the plating covered with rust scale, which, on removal, is seen to be actually harbouring water, the cement and scale themselves appearing dusty and dry; and very commonly, on breaking away thin marginal cement, dirty water will flow from between it and the plating. Unless marginal cement is at least 1 inch thick, it would be better away, for then the condition of the plating, whether rusting or not, would at all times be observable, and an anti-corrosive coating of cement wash or paint applied as required.

Good cement becomes as hard as a rock; to remove it during damage repairs may involve much labour. A thick covering confers much strength and rigidity to the bottom plating; small vessels which frequently take the ground are found to receive from it valuable support. It also gives some security against leakage; many cases are on record where the bottom shell plating has been injured, and the cement, being unbroken, has prevented the entrance of water; and a ballast tank, the top of which is corroded through in holes, may be kept quite tight by a covering of cement. Although very brittle, cement may yield considerably before fracturing; should water get below thin cement, it may gradually force it to assume a blister-like convexity. And in cases of grounding, though a vessel's bottom may be set up very perceptibly, the cement may show no evidence of the disturbance; nevertheless, its contact with and adherence to the plating may, of course, be prejudiced. The quality of the raw cement is not often tested in the shipyard, and it is not unlikely that, where

small quantities are indirectly supplied, much of it may be inherently bad, a circumstance which may not be discovered for years afterwards. In cementing a ship's bottom, only small quantities should be gauged at a time, it should be laid in place without delay, the sand and cement should be carefully mixed, the plating should be free from oil and should be wetted or cement-washed before the cement is laid upon it; frosty weather should be avoided, for if the cement be frozen before it becomes thoroughly hard, its adhesion may be spoiled. It should be observed, however, that, as regards concrete work on shore, frost is not found to affect the efficiency of the work.[1]

Art. 477. The circumstance that cement must be thick, in order to give thorough and permanent protection to the shell plating, detracts considerably from the vessel's weight-carrying power. In some cases, therefore, this is avoided by substituting a thin covering of **bitumastic cement, or asphalt.** This is applied in a hot, molten state, being laved over the sloping parts of the bottom until, by cooling, it accumulates sufficiently to cover the rivet heads. When well applied it penetrates every crevice, and as it adheres with persistence to the steel, it forms a good anti-corrosive covering; nevertheless, it has several objectionable characteristics, which make it very inferior for general purposes to good Portland cement. For although it forms an excellent anti-corrosive covering, it is too thin to give substantial protection against the erosive action of loose stones, etc. And it is usually defective as regards permanence, for if its nature is such that it does not become brittle and crack it may at times become so soft as to flow, leaving bare the sloping parts of the bottom and rivet heads, and accumulating in thick masses elsewhere. Another fault is the tendency to decompose and rise in blisters, large and small, which, when broken, are usually found to contain water, but in some cases inflammable gas. The latter circumstance is a serious matter, for it sometimes happens, when the inside of a double bottom tank is being examined by candle light, that the breaking of a blister is followed by an explosion, to the danger of the investigator.

The fact that asphalt does not afford substantial protection against erosive action is comparatively unimportant in the case of a double bottom, for here loose stones, etc., are rarely if ever present. But to apply molten asphalt in an enclosed tank is impossible, for the fumes would asphyxiate the men; when adopted in new ships it must be applied before the tank-top plating is fitted. In such cases, should it become defective at any time, it cannot be renewed; and to substitute Portland cement is a costly affair, for, to secure proper and permanent adhesion, every particle of the tough and firmly adhering asphalt must first be chipped off. Asphalt was employed as a substitute for cement in some of the earliest iron vessels, but it was found to be unsatisfactory. Later it was again introduced, but at the present time its employment is very limited, for as none of the asphalts available are free from one or other of the above defects, their adoption has usually been followed by trouble and expense. The bottom plating of warships is coated inside with black varnish; and this is also sometimes employed within the double bottoms of merchant vessels.

[1] See *Engineering*, September 29, 1899.

PART II.

CHAPTER XXXII.

Art. 478. Before the actual building work of a ship is begun, she must be designed and constructed, so to speak, on paper, so that each plate and bar may be measured and ordered from the steel works, and so that the various parts may be properly shaped and put together by the workmen. The dimensions, displacement, and general features of the ship are, of course, determined before any plans are drawn; and this preliminary work is exceedingly important, for upon it depends the capabilities of the ship for the work required of her. The responsibility of the builder in producing a successful ship varies according to the data supplied him by the owner; in some few cases little is left to his judgment, the dimensions and every other particular being specified; in others the design may be left entirely to him, he may be asked merely to build a ship of a certain type, capable of carrying so much cargo—measured by weight or bulk—at a certain minimum speed, on a certain length of voyage. The question of cost is, of course, a ruling one in deciding the dimensions and other particulars, for while the simple plan of building a large ship, having ample engine power, might ensure the accomplishment of all the owner's requirements, it would be costly. The success of the builder depends, therefore, in great measure, on his constructing a ship which will only just satisfy the conditions laid down by the owner; if these are not quite attained, the latter may refuse to accept her, and, if exceeded, the builder gives more than he was asked, or bargained to give.

The first plan to be made is the **'midship section**; this not only indicates the cross form of the vessel's hull, but shows the general structural arrangement and the scantlings of the various parts; it is, in fact, a sort of illustrated specification of the main structure of the hull (see Plates 100 to 107). If the ship is to be classed with Lloyd's or other classification society, the scantlings, etc., are, of course, arranged in accordance with their rules, the plan of the 'midship section, etc., being submitted for approval.

The form of the hull must next be determined and indicated on a plan termed the "**sheer draught**" **or** "**lines**" (Fig. 77); then, from this as a copy, a wood model is made, usually on the same scale, namely, $\frac{1}{4}$ inch to the foot. In a full-lined cargo boat, when the dimensions, displacement, and the form of the 'midship section are determined, the designer has not much option as regards the form of the under-water hull, for it departs but little from a rectangular solid. On the other hand, in a fine-lined, high-speed vessel a great deal of latitude is allowed, for she may be made full here and sharp there, or flat at one part and round or hollow at another, variations which, while not affecting her displacement or carrying power, may greatly alter her form as regards appearance, resistance, and behaviour at sea. In many cases the owner requires the builder to submit, in the first instance, a **model** of the hull for approval. The sheer draught is of fundamental importance, for as it is from it that the form and dimensions

of every part of the hull are ascertained, it is constantly referred to by the draughtsman when arranging and ordering the plates and bars, and when giving to the workmen the necessary information for the shaping of the different parts. For the latter purpose, it, or a part of it, is drawn out full size, a procedure termed "laying off."

Notice briefly the principles which govern the **method of depicting on paper the form of a vessel's hull.** To indicate in a drawing the shape of a solid there must be at least two views of it; thus, the shape of a rectangular box could not be determined from its plan alone, *i.e.* from a view of its top, for only its length and breadth dimensions would appear; to indicate its third, or depth dimension, an elevation either of its side or end must be given. Further, while only two views would provide all the necessary data as to the dimensions of the box, they would not readily convey to the eye its precise form; for this three views are necessary—a plan, a side elevation, and an end elevation. In the sheer draught of a ship (see Plate 77) these three views are given: the plan, usually referred to as the "*half-breadth plan;*" the side elevation, or "*profile;*" and the end elevation, or "*body plan.*" In the case of a rectangular box, the form in each view is fully indicated by the outline only, for the surface of which this is the boundary is a plane. In a ship, however, a single outline would give no idea of the form of the curved surface lying within it. To depict this the hull must be assumed to be cut up into numerous parallel layers, or sections, for then the outline of each layer (all of which are drawn) will represent the contour of the hull at each place. The block of wood from which the ship's model is hewn is composed of horizontal planks about 1 inch thick, glued or screwed together. When the model is viewed sideways, or endways, the junctions or contour lines of the planks appear as parallel straight lines, but when viewed from above, the model being keel-up, they appear as curved lines—termed "*water lines*," or "*level lines.*" If, now, the model, when viewed keel-up, were crushed flat, without lateral deformation, its original solid form would still be discernible from the unchanged curved form of the water lines; and, being no longer a solid, but a plane, it would be identical with the half-breadth plan of the sheer draught.

The water lines are curved only in the half-breadth plan, in the profile and body plan they are straight. To show in the profile the curved form of the hull, another set of layers or sectional planes must be assumed; here they are disposed fore-and-aft, and perpendicular to the vessel's deck or water lines. Their contour lines are termed "*buttock lines*" (properly speaking, those forward of 'midships are termed "*bow lines*"), and, as shown in Plate 77, they are curved only in the profile, for here they are parallel to the plane of the paper, whereas in the half-breadth and body plan they are perpendicular to it, and, of course, whatever be the outline of a plane, it appears as a straight line when viewed end-on.

To show the curved form of the hull in the body plan, still another set of layers or sectional planes must be assumed, which in this case are disposed in transverse, vertical planes. Here the contour lines are not necessarily imaginary, for they may represent the vessel's frames (they are termed "*frames*," "*sections*," or "*stations*"), and, of course, as before, they appear as straight lines in the profile and half-breadth plan. It will be observed that in Plate 77 one side of the body plan represents the forward half of the vessel, or "*fore body*," and the other the "*after body.*"

Every one of the numerous points of intersection of the buttock, frame, and water lines appear in each of the three views of the hull, and if the three views are properly drawn, *i.e.* if each one represents the same

ship, viewed merely from different aspects, the three representations of any particular point must occupy the same position in space; that is to say, they must be the same longitudinal distance from the bow, the same athwartship or transverse distance from the fore-and-aft centre-line plane, and the same vertical distance from the top of the keel, or base line (see points P and Q shown in the three plans in Plate 77). The position of a point in any particular view can, of course, only be observed and checked as regards two of these measurements; for fore-and-aft distances cannot be measured in the body plan, nor breadths in the profile, nor heights in the half-breadth plan. It will be observed, by making measurements on Plate 77, that the points of intersection of each water line with each buttock occupy the same fore-and-aft position in the profile and half-breadth plan, and that they also correspond, as regards height, in the profile and body plan, and, as regards breadth, in the body plan and half-breadth plan. It follows, therefore, that if these points are situated on the surface of the hull, the surface indicated by them must be fair and regular in every direction, because curved lines (buttock, frame, and water lines) drawn through them in three directions, and which, of necessity, must also be on the same surface, are fair and regular.

The buttock, frame, and water lines represent the lines of intersection, or "traces," of three sets of planes (vertical-longitudinal, vertical-transverse, and horizontal) with the vessel's hull. But, besides these, the traces of any other plane may be shown; thus, in Fig. 3, Plate 77, the line AA represents a fore-and-aft **diagonally disposed plane.** Its trace in the profile and half-breadth plan is shown by the curves AA (obtained in the usual way, by measuring in the body plan the heights and breadths of its points of intersection with the frames); these, however, do not show the true form of the vessel's hull where cut by the diagonal plane, nor, of course, the true form and length of the curved trace. This is shown by the curve A′A′ on the half-breadth plan, which is obtained simply by measuring on the line AA, in the body plan, the diagonal distances from the centre line to the points of inter-section with the various frames, and setting them off on their respective frames on the half-breadth plan. The diagonal line, or plane, under consideration is usually referred to as the "**bilge diagonal;**" it will be observed from the body plan that it passes through the intersection of the rise-of-floor and half-breadth line, and the load-water and centre line. It is a particular useful line in the work of drawing and fairing the sheer draught, for as it meets the frames squarely, the points of intersection are definite and easily located, which is not the case, for instance, with the lower water lines and inner buttocks. It is also useful in that the vessel's displacement may be readily approximated from the area of its plane (as contained between its true contour and the centre line in the half-breadth plan), for this is dependent on, and is affected by, all three dimensions, length, breadth, and depth; the area of a water-line plane, for instance, can give no indication of the displacement, for it is unaffected by the depth or draught of the hull.

The foregoing describes the finished **sheer draught.** Notice now **how it may be drawn.** It will be assumed that the outline of the profile, and of the upper deck in the half-breadth plan, are already drawn, as also the various straight water lines and frames. What is now required is to indicate by curved lines in the body, and half-breadth plan, the surface of a well-shaped ship, which shall have the specified displacement or volume. As the draughtsman in drawing these lines judges of their suitability by the eye, he must be familiar with the general form of the vessel as regards fulness or fineness. The precise degree of fulness or

fineness is ascertained by dividing the displacement in cubic feet (*i.e.* the volume of the under-water hull) by the volume of the rectangular tank which will just enclose the under-water hull when denuded of its shell plating and keel. This fractional figure is termed the "*coefficient of fineness*," it expresses how nearly the hull approaches the full form of a rectangular tank; if it were of the same fulness, *i.e.* if it itself were a rectangular tank, the two volumes when divided would, of course, give unity; if it occupied only half the volume of the tank, the coefficient would be 0·5, and the volume of the tank (*i.e.* the product of the length, breadth, and draught of the ship) multiplied by the coefficient 0·5, would, of course, give the displacement of the ship in cubic feet.[1] In fine-lined yachts, the coefficient may be as low as 0·4; in full-lined cargo boats, it may be as high as 0·83.

The **procedure** followed by the draughtsman **in drawing the lines** depends on his experience and methods. To an expert, the form of the curved water lines and sections is so familiar, that he is able to draw, with little hesitation, a suitable load water line in the half-breadth, and a few intermediate sections in the body plan, which, when tested, will be found to represent not only a fair hull surface, but one not very much astray as regards fulness or fineness. To test whether or not the sections roughly drawn in the body plan represent a surface which is fair longitudinally, the breadth of each one at each water line, or intermediate water line, is set off on the half-breadth plan, and curved water lines are run as nearly as possible through these points; it will be found that some points are too far in or out relatively to their neighbours, which means that these particular frames on the body plan are too lean or too full. Having drawn the water lines from the roughly drawn frames as a basis, the procedure is reversed, the frames being corrected or drawn afresh from the water lines as a basis; and if this process is continued, and curved buttock lines or diagonals are also drawn, it will soon result in a perfect correspondence in all three sets of curves, *i.e.* in the delineation of a perfectly fair hull. But, before troubling to secure this result, the **displacement** must be checked by calculation, which in the first instance need only be approximate. This is done by computing the areas of the transverse sections, by planimeter or by the well-known rules for the mensuration of areas bounded by curved lines,[2] and subsequently finding the area of a plane bounded by a curve, the length of whose ordinates is represented by the areas of the sections just found, and whose length is that of the ship; the result being the displacement (or half displacement) in cubic feet. As the lines, so far, have only been drawn in to the eye, in a tentative fashion, it is not to be expected that the displacement will be exactly what is required, but when the discrepancy is known, a skilful draughtsman may very quickly so fill out or reduce the breadths of the various curves as to add, or take away, the deficit or surplus volume.

The speed and accuracy of the work when done in this way is, evidently, entirely dependent on the skill and experience of the draughtsman. But there are various well-known mechanical methods by which a fair hull, of any required degree of fulness or fineness, may be delineated with considerable precision in the first instance without the need for special skill or experience in the draughtsman.[3]

[1] The actual displacement of the ship would be rather greater, due to the increase in the bulk of the under-water hull caused by the shell plating.

[2] Instruction in this matter will be found in Mr. Thearle's work on *Theoretical Naval Architecture*, also in that of Mr. Attwood.

[3] An excellent rule, in which the bilge diagonal is used as a basis, will be found in Mr. R. Zimmermann's paper, "*A method of obtaining the desired displacement in designing ships*," *Trans. Institution of Naval Architects*, 1883.

In shipyards where plans and particulars of numerous vessels of various types are available, the work of drawing the lines of a new ship is usually done rapidly and surely by using the lines of another as a copy or basis. A ship, for instance, may already have been built, which, although larger or smaller, may be practically of the same proportions and fulness; in which case her lines, when reproduced on a smaller or larger scale, may serve, with perhaps some small modification, for the proposed vessel. Or if a ship has already been built, having the same coefficient of fineness but, say, 20 per cent. greater length and draught and 10 per cent. greater beam, then if her lines are reduced 20 per cent. in length and depth (by contracting the intervals between the sections and water lines), and her curved water lines or sections 10 per cent. in breadth, the result will be a fair ship of the required size and displacement.

Art. 479. When the sheer draught is completed satisfactorily, the next operation is to enlarge it, so that a **full-size body plan** may be provided for the workmen as a guide in bending the frames. This body plan is drawn down on a floor of stout boards, termed the "**scrive board**," which is situated close to the bending slabs. Every frame is shown, and in a permanent manner, by a narrow groove, or *scrive*, cut on the surface of the floor with a sharp tool, termed a "scrive knife." The body plan of a sailing-ship and of a small steamer, as scrived on the boards (with some lines omitted), are illustrated in Plates 78 and 79. In many yards the body plan is scrived in from measurements taken direct from the sheer draught. If the latter is on a small scale, however, any discrepancy in the fairness of its curves, or in the measurements taken from it would become greatly magnified in the full-size drawing—48 times if the sheer draught is on the usual scale of $\frac{1}{4}$ inch to the foot. Accordingly, when this method is adopted, the chance of error must be minimized by drawing, in the first place, a large-scale body plan ($\frac{1}{2}$ or $\frac{3}{4}$ inch to the foot) showing numerous frames, and carefully checking it as regards fairness. Sometimes, to ensure fairness, the lines are drawn on the same large scale as the body plan. In a celebrated shipyard on the Tyne they are drawn on a scale of 1 inch to the foot, on immense slabs of white marble, the smooth surface of which admits of fine penmanship and ready erasement.

In most high-class shipyards, the entire sheer-draught is laid off full size, in chalk (cut in thin slices and hardened by baking), on the blackened floor of a large shed, termed the "*mould loft*." This is advantageous in many ways: owing to the large scale, perfect fairness in the body plan is secured; various pattern moulds may be made showing the shape of different parts of the hull; and battens and templates, giving precise information as to the sizes and disposition of the various structural parts, may be provided for the use of the workmen. It should be observed that, as the mould loft is rarely long enough for a full-length drawing of a vessel, the fore and after bodies in the profile and half-breadth plans are drawn separately, the one on the top of the other, and usually on a reduced longitudinal scale. The loftsman, whose duty it is **to lay off the ship**, receives from the drawing office such measurements from the sheer-draught as enable him to reproduce it full size. Having drawn the outline of the profile, and struck in (with chalk-line) the various straight constructional lines, the next operation is to set off, on the half-breadth plan, the breadths of the various water lines and decks, as supplied at every fifth or sixth frame from the drawing office. Curved lines are then drawn through these spots, or as near to them as is compatible with perfect fairness, by means of long, tapered, wooden battens, which are held to the proper curvature by long, flat-headed nails, driven into the floor alongside. Some of the breadth spots will be

wide of the water line just drawn, by an inch more or less, and the next operation is to measure the amended breadths, set them off on the body plan, and run frame curves through them; and if some of the latter curves pass clear of the spots, the water lines are corrected to correspond, and then again, the frames, if necessary, until a perfect correspondence is secured. The work of measuring the breadths and heights on the mould-loft floor is facilitated by making the centre and base line coincident with the side of a long straight-edge, permanently fixed on the floor, so that when the end of the measuring batten is held against this, it is certain that it lies exactly over the centre, or base line. In fairing the sections, the buttock lines and diagonals are also used, because the horizontal water lines afford but a poor check on the fairness of those portions of the frames which approach the horizontal—as on the vessel's bottom amidships, and under the quarters or buttocks. As yet, only every fifth or sixth frame is laid off on the body plan, and now the remainder are run in, by measuring their breadths from the corrected water lines and their heights from the buttocks, and as these lines are now perfectly fair, this is straightforward work.

The next operation is the simple one of transferring the completed body plan to the scrive board (see Plates 78 and 79). For this purpose the various breadths, heights, and diagonal distances are carefully marked in pencil on any one of the four sides of long battens, 1 inch square in section. The height of the deck beams at each frame are also noted, and such other measurements as are necessary for accurately transferring the various curves to the scrive board. Having served their purpose, these battens are usually preserved so that, should it be required at any time to build a duplicate ship, the laying-off work may be saved, for, of course, the battens embody practically all the information for which this work is undertaken.

It will be noticed that the only useful purpose served by laying off the water and buttock lines in the half-breadth and profile, is to check the breadth and height measurements supplied from the small-scale sheer draught; now, as in these two plans only breadths and heights are dealt with, it is evidently immaterial whether the frames on which they are set off are the full distance apart or a smaller distance; that is to say, it does not matter whether the length of the ship, as indicated in the profile and half-breadth plan is laid off full size or on a **contracted scale**, of, say, one-quarter, one-third, or one-half full size. This contracted method of laying off is generally adopted, for it has many advantages; it permits of a large ship being laid off in a small loft; it is easier to fair the lines, because, owing to the foreshortening, they have a greater curvature, and a good, flexible batten, when *sharply* bent, assumes naturally a fair curve; there is less confusion where the numerous lines gradually approach and cross one another, and, owing to the smaller fore-and-aft distances, the laying off work is less laborious. Of course, when the profile is contracted, a properly shaped stem, stern, and stern-frame must be drawn separately, for making the moulds, etc., for these parts.

Art. 480. The spacing of the frames is indicated on the vessel's keel, so that the lower part of each one, as it is erected, may be fixed in its proper fore-and-aft position. Their upper parts are fixed temporarily together, at the proper distance apart, by fore-and-aft **ribbands**, one near the gunwale and others between this and the keel. In fixing them to the ribbands, their spacing might be adjusted simply by measuring the *fore-and-aft* distance between them, for which purpose thwartship lines would have to be stretched across those frames which varied in breadth. Sometimes this procedure is adopted, but in most

cases the position of each frame is previously marked on the ribbands, their spacing as measured on these (which, of course, is variable) being supplied to the shipwrights from the loft on long battens. To prepare these battens, the loftsman first draws in the ribband lines on the body plan, taking care not to place them in way of the inner strakes of shell plating, the side stringers, or keelsons. They are also shown on the scrive board (Plates 78 and 79), in order that their vertical position may be nicked in on each frame. The loftsman must now expand these ribband lines, so as to obtain their true length and the position of the various frames upon them. When straight on the body plan this is a simple affair, for they may be expanded in the half-breadth plan by merely measuring diagonal breadths, and as the curved lines so obtained appear in full length, the battens may at once be applied to them, and the position of the frames marked for the use of the shipwrights.

If the ribband lines are curved in the body plan, their true length may be obtained as follows. In Fig. 2, Plate 94, AF is the ribband line as it appears in the body plan. In Fig. 1, A′F is the same line, as it appears in the half-breadth plan, and as obtained from Fig. 2 by measuring horizontal breadths at each frame; it does not here appear in its full length, however, for while the point F is in the plane of the paper, the point A′ is the height A*a*, Fig. 2, above it. To show it in full length it is first expanded horizontally, by applying a batten to it (to A′F, Fig. 1), marking on this the position of the frames B, C, D, etc., and then springing it out on any straight line, as AF, Fig. 1, and transferring thereto the various frame marks. Now, the point A′ or A, Fig. 1, is shown in Fig. 2 to be above the level of the point F (or the plane of the paper) by the height A*a*, and the heights of the intermediate points B, C, D, etc., are also shown, and accordingly, if, in Fig. 1, these heights are set off, each one as a perpendicular, then a curve, *a*F (Fig. 1), drawn through them will be the correct expanded length of the ribband, having upon it the proper position or spacing of each frame, and from which the ribband battens and ribbands may be accurately marked. In practice, it is usually found quite sufficiently accurate to make a simple expansion of AF as seen in the body plan, treating it as a diagonal, by measuring breadths *along it* instead of along horizontal water lines.

Art. 481. As noticed in Art. 81, the two flanges of all frames beyond the 'midship, flat body are bevelled, and not only is the bevel of every frame different, but it varies throughout the length of each one. The bevels may be "lifted" by the loftsman as a final operation on the scrive board, and are given to the workmen on **bevel boards**, one of which is shown in Fig. 11, Plate 80; otherwise the workmen may lift them themselves, for each frame, as required. What is wanted is the bevel of each frame at intervals of four or five feet in its length. For this purpose, the loftsman sometimes scrives in a few diagonal, or **bevel lines** across the body plan, the intersections of which, with the frames, indicate to the workmen the points in each one at which the various bevels must be applied in the actual bevelling work; otherwise the water lines, shell landings, or ribband lines are made to serve as bevel lines. The lifting of the bevels is a simple operation. Fig. 11, Plate 80, represents part of a scrive board with two frames scrived upon it. Now, if the frames are spaced 2 feet apart in the ship, the actual relative positions of the two frames in Fig. 11 are shown by their sections in the upper sketch, and the bevel of frame 5 is shown by the angle *b*. The bevel of any frame at any point may, therefore, be obtained merely by setting up a perpendicular, ED, in length equal to the frame spacing, at one end of the short line, CE, drawn squarely

between the particular point and the adjacent frame, and completing the triangle, CED. In the lower sketch, Fig. 11, there is shown a contrivance for lifting the bevels, which, when considered in conjunction with the upper sketch, explains itself.

Art. 482. Notice now some of the more important practical operations of the drawing office. On the completion of the sheer draught the model and working drawings may be made, and the structural material measured for ordering from the steel works. The latter operation is usually referred to as the "**ordering of the material.**" The various plates and bars cannot, of course, be ordered of the precise finished dimensions, for these are not known until the parts are actually about to be fitted in place in the ship. What is aimed at is to order them of such a size as will provide just sufficient margin for inaccuracies in the measurements made from the small scale plans and model, and for slight differences in the shape of the part as shown on the plans or model, and as fitted in the ship. If a part is ordered too small, it is, of course, useless for its intended purpose, and before another is procured serious delay may occur. If the ordered dimensions are much in excess, the surplus material removed in shaping the part will be large, and as this **scrap steel**, when returned to the steel works, only fetches about one-third of the price originally paid for it, the loss in each ship may be considerable. The material is weighed as it leaves the steel works, and the weight is entered in the invoice; the difference, therefore, between the invoiced weight and the weight of the steel worked into the ship represents the total waste or scrap. The percentage of scrap varies with the care and skill of the draughtsman who orders the material; 7 per cent. is a low figure, 11 per cent. is a high one. It may be minimized if, instead of measuring all sizes from the small-scale plans and model, accurate measurements are obtained from the full-size lines in the mould loft. The more important measurements are usually checked in this way, but not always, for, where great expedition in building is required, it may be inadmissible to postpone the ordering of the material until the laying-off work is completed.

Notice some of the more important matters in connection with the ordering of the material. As regards the **frames**, only a few are shown on the body plan, but when their lengths are measured with a flexible batten, and set off on paper as ordinates from a base line, a curve drawn through the spots at once permits of the intermediate ones being correctly measured. The lengths of the frames are usually measured on the heel, and as the outer flange of the frame angle stretches considerably during the bending process, little or no margin of length is required. In the case of the side frames, however, when deep and stiff they should be ordered from 9 to 12 inches long, because it is impracticable to bend them properly, right up to the end. The **reverse frames** may be set off in a similar way, on the same expansion plan, but as they contract slightly during the bending they must be ordered full, *i.e.* assuming them to be measured on the line of the heel.

Plates as ordered from the steel works may be tapered on one or both sides (Figs. 13 and 15, Plate 80), or on one or both ends (Figs. 14 and 16), in which cases one length and two breadths, or two lengths and one breadth are given in the order, with a statement of the nature of the taper. Or they may be of quite an odd form, in which case a sketch with figured dimensions must be provided (Fig. 17). As the cutting of oddly shaped "sketch-plates" involves extra labour and waste at the steel works, an additional charge is usually made should there be an excessive number of them.

To order the **floor plates**, they must first be outlined in the body plan; this and other work of the kind being conveniently done on a sheet of tracing paper, spread over the sheer draught. The shape of a shallow floor as ordered, is shown in Fig. 1, Plate 82. An expansion sketch is made for each of the few floors outlined in the body plan, and then the similar dimensions of each one (which, of course, should vary gradually) being set off as ordinates, curves run through them at once permit of the dimensions of all the intermediate floors being measured. In the specification, or order sheet, sent to the steel works, one diagram suffices for all sketch-plates of similar outline, with, of course, a tabulated statement of the variations in the lengths of the different edges, the different thicknesses, and identification marks.

The **shell plating** is ordered from the model, for which purpose the frames and various strakes are drawn upon it, fair to the eye, by means of flexible battens, the end joints being arranged in such a way as to give a good shift with themselves, with the joints of the deck stringers, and with any other transverse lines of possible weakness. The loftsman then receives a note of the position of the landings (by girth measurements), so that he may lay them off on the scrive board for the information of the workmen. As here shown, some of the landings may present, at places, a curiously crooked appearance; this is due, of course, to excessive foreshortening (a length of 1 inch or so on the scrive board may represent a distance of 100 feet or more in the ship), for the same line when regarded on the model or ship may be a perfectly fair curve. The shell plating being an undevelopable surface, cannot be properly depicted in a plan, just as a map of the world gives a very distorted presentment of the various continents. Nevertheless, an expansion plan is usually drawn (Plate 90), for it is an excellent means of showing, graphically and clearly to the workmen, the peculiarities and characteristics of each plate.

The length of each plate and its breadth at either end are measured from the model. The change in the breadths in passing from plate to plate should be gradual, and to check the measurements, it is, therefore, well to set the breadths off as ordinates and run curves, an operation which may be conveniently done on a sheet of foolscap, using the ruled lines as ordinates. In most cases the breadths of each strake, at the end of each plate, are obtained from the scrive board, which permits of the plates being ordered more nearly of the correct size, and thus minimizes scrap. Many of the plates are rounded on one or both edges, in which case the amount of divergence from the straight must be carefully ascertained from the model, and added to the end breadths. If the breadths are procured from the loft, the margin generally allowed in the ordered breadths is about $\frac{1}{2}$ inch for the inside strakes, and 1 inch for the outer ones, with rather more for the bilge strakes, and considerably more for oddly shaped plates at the stern. The length allowance is from $\frac{1}{2}$ to 1 inch, but rather more for plates at the ends. It is well to allow rather more length in the plates of the outside strakes, so that their ends may be kept clear of the edge holes of the inside strakes.

The **keelsons and side stringers** are also drawn on the model, care being taken that, where practicable, they do not cross the landings of the shell plating, and that they are not more widely spaced towards the bow and stern than they are amidships. The loftsman is provided with a note of their position, just as in the case of the shell landings. Besides this, many other features affecting the shell plating may be conveniently shown on the model, such as the decks, the joints of the stringer plates, the bulkheads, tank tops, doubling plates, cargo ports, sidelights, etc.

For the purpose of identification, every plate and bar is ordered under some **distinguishing initial letter and number,** which are painted on them at the steel works. Thus, the frame angles are usually marked F1, F2, etc.; the reverse bars, R1, R2, etc.; tank-top plates, T T; upper-deck plates, U D; bulkhead plates, B H, etc. Different strakes of plating are usually identified by letters, in the case of the shell, for instance, A represents the garboard strake, B, the next; and the plates in each strake are numbered consecutively, beginning from the stem or stern. Besides these marks, the ordered dimensions of each plate and bar are painted on them at the steel works; and as each part is delivered in the shipyard, its size and thickness are carefully checked, similar parts being stacked or laid together in separate batches under a travelling crane, so that they may be easily found, lifted, and taken away by the workmen. If the steel has been tested by Lloyd's Register, every plate and bar is stamped with the Society's well-known monogram (the letters LR superposed), or if tested by the Bureau Veritas or British Corporation, with their monogram or initials; and, to ensure that only tested material is received into the shipyard, these stamp marks should be looked for and examined.

CHAPTER XXXIII.

Art. 483. Before describing the operations connected with the bending or setting of the frames, it will be well to notice the information supplied to the workmen, and some of the shipyard plant necessary for the work. The **scrive-board** has already been described, and the two bodies of a sailing-ship as scrived upon it are shown in Plate 78 (for clearness' sake some of the frames have been omitted). As the frames on both sides of the ship are alike, only one side need be shown in each body; when there is a cellular double bottom, however, the lower part, in way of it, is usually drawn in full. In vessels of unusual or complicated structural design, such as warships, both sides are scrived in. Scrive boards (Fig. 11, Plate 80) may be of pitch pine, yellow, or white pine. Pitch pine is the best, for its surface does not tear under the scriving knife even though the lines be close together, and, as it is hard, the lines are not readily effaced by wear. Inferior boards are roughly made of white-pine boards. A good solid board may be made with deck planks. The most efficient are made of pitch-pine planks, about 11 by $2\frac{1}{2}$ inches, built in large hatches, and jointed with metal dowels, so that they may be put together temporarily in the loft, and, on the completion of the scriving work, taken to pieces and united again, precisely as before, in the frame shed; in this way time may be saved, and the frame-setting work of various vessels carried on without intermission. After the frames of a ship are finished, the scrive board may be planed and blackened for another; often, however, it is not planed, the body plan of the new vessel being scrived in over that of the old, which by this time is usually almost obliterated. To preserve the surface of the board from the wear and tear due to the repeated application of heavy framing material, thin strips of iron are sometimes nailed across it.

Art. 484. The scrive board does not show the structural arrangement of the frames, but merely their curvature and the position on each one of the shell landings, side stringers, keelsons, deck beams, floors, etc. The necessary detailed information is supplied to the men in a **frame list**, and a plan of the 'midship section and profile. The frame list is a tabulated statement fully describing the peculiarities of each and every frame. It takes account of, and indicates the following matters. The scantlings of each frame angle, reverse bar, and floor. The height to which the reverse bars extend. Those frames which have to be cut at watertight deck flats, or at cargo ports, scuppers, etc., and those which have heel pieces at the centre line, or are doubled at any parts, and to what extent. Those to which beams are attached, with the depth of the beam knees, and the number and size of the connecting rivets. Those which are of web type, and those to which watertight and other bulkheads are attached. Those whose shell flange is reversed for special reasons, or whose floor plates require to be punched for intercostal plates. Those in the machinery space which have double reverse bars, and in which special rivet holes are required for

the attachment of the engine seating, boiler and shaft stools, etc. The connection to the margin plate is also described, whether by single or double lugs or by gusset plates. The spacing and size of the rivets is also given for each part of each frame, and the spacing of the bolt holes in the reverse bars for the ceiling, planking, and sparring. Together with this information detailed sketches of odd parts, with dimensions, should be given, so that, as each frame is taken in hand, the men may, by noting its peculiarities on the list and in the profile plan, construct it exactly as required. The neglect to provide sufficiently full information may, of course, lead to considerable trouble and expense, through the necessity of making alterations, subsequently, when the various parts of the hull are put together.

Art. 485. The **bending slabs**, or **blocks**, on which the red-hot frames, etc., are bent, form together a solid cast-iron floor (see Fig. 5, Plate 82, and Figs. 5 and 6, Plate 83). The individual slabs vary in size; in Scotch yards they are usually from 5 to 6 feet square, by 5 or 6 inches thick. Thickness is advantageous, not only in giving anvil-like solidity against the blows of heavy hammers, but in reducing the tendency to deformation; for, owing to the heat and the constant hammering, the upper surface of the slabs expands laterally, and, in doing so, becomes convex, *i.e.* each slab bends gradually upwards in the centre; in the course of a couple of years, 6-inch slabs may become rounded to the extent of half an inch. In practice this tendency is corrected by periodically turning them upside down. The slabs are pierced with holes, from $1\frac{1}{2}$ to $1\frac{3}{4}$ inches in diameter, about 4 inches apart (Fig. 5, Plate 83). In shipyards on the north-east coast of England the holes are square (Fig. 6). Square holes are superior to round in that, as square pins cannot turn in them, they greatly facilitate the "*making up*." With square holes, the making up may be precisely the same as with round ones, but it may also be made with square-section, L-headed pins (see P, Fig. 6); and a wedge-shaped locking-pin may be inserted in the hole alongside of a square pin (as shown at E, Fig. 6), so that the latter, being deprived of side play, may not turn, but stand rigidly to its work.

The surface of the slabs, as a whole, should lie in one plane, so that when the frames, etc., are hammered down flat upon them, they also may be in one plane. As the slabs form together a very heavy mass, they must have a solid foundation, to avoid subsidence and unfairness of surface. There must be an open space below them, so that the scale and slag which drops off the hot bars, and other small objects, may fall through and not choke the holes. They may be supported at the corners only by short vertical blocks, sitting on cross logs, otherwise they may sit on low foundation walls of brick or concrete. To prevent the slabs from shifting under the severe lateral forces brought to bear when bending heavy frames and stem bars, the outer rows are tied together by cross bars running underneath; contiguous outer slabs being connected by edge fish-plates.

The frame angles are heated in a long, flue-like **furnace, of reverberatory type**, heated by coal fires placed in side chambers at intervals throughout its length. Only flame and heated gases enter the furnace proper, and, after passing from end to end, they turn back under the floor, heating this still further on their way to the chimney. The stoking or firing must be carefully done, so that the furnace may be maintained as nearly as possible at an equal temperature throughout; if much hotter at one part than another, a frame bar, in course of heating, might be overheated or burned at one part, while insufficiently hot at another. Some modern

frame and plate-heating furnaces are constructed on the *regenerative principle* (Art. 566), this being advantageous as regards economy in labour and coal, and in securing more uniform heating of the plates and bars.

Art. 486. The work of making the frames is undertaken by a **frame squad**, who are paid by agreement, so much per frame. The squad consists usually of five or six platers, assisted by a number of skilled labourers or helpers; and the work is apportioned among them into various sections or departments, a division of labour which tends to expedition, ease, and accuracy in the work.

The first operation is to **punch the rivet holes in the frame bars.** It is, of course, easier to do this before the bars are bent and bevelled, for, if done afterwards, the holes in the shell flanges would have to be punched in a horizontal machine, which, with curved bars, is a tedious operation, and, with bevelled ones, almost impracticable. The holes in the bilge portion must be omitted until the bar is bent, for, if not, they would become oval with the bending (see Fig. 18, Plate 80); the tendency is particularly marked when the bilge is sharply curved, and with deep frames, or those formed of bulb-angle, channel, or Z bars. The distortion of the holes in the shell flange is due, of course, to the extension which, of necessity, occurs with the bending; the distortion of those near the toe, or tip, of the transverse flange being due to compression. The compression of the toe of an angle bar greatly exceeds the extension of the shell flange, for it is further away from the neutral axis; holes placed near the toe of a deep bar may almost collapse under the bending, for the greater part of the compression then takes place in the little piece of metal between the edge of the bar and the holes, where there is the least resistance (Fig. 18). If placed well back from the toe, they do not suffer so much; if on the neutral axis, not at all. It is hardly necessary to indicate the objectionable nature of oval rivet holes, for it is evident that as the rivets are not likely to fill them solidly, they may strain and loosen under a comparatively small stress. They are more particularly objectionable in the case of the shell rivets, for if these should loosen, water would enter the ship. The rivets connecting the frame angles, reverse bars, and floors are very commonly closed by hydraulic power, in which case a slightly oval form in some of the holes is less important, for a machine rivet may fill even an unfair hole perfectly solidly, and holes that are distorted by compression may be well corrected with the drift.

The work of **marking the rivet holes in the frame angles** of a ship having shallow floors, such as that shown in Plates 100 or 101, is done as follows. Having made one of the frames on the scrive board (Plate 78) conspicuous with chalk, the workman places a long flexible batten on the scrive; starting from the top or deck end, each part of the batten is held momentarily and successively to the scrive, and, while in position, the various shell landings, decks, side stringers, and the floor head are marked upon it. Now, during the operation of bending the frame, its shell flange stretches at the bilge, and it follows that if the landings, so marked on the batten, were transferred to the frame angle, they would not, after the latter was bent, correspond in position with those on the scrive board, because those on the bilge portion would have drawn asunder. This is provided against in the marking of the batten; for as each landing on the curved bilge portion is chalked upon it, it is slipped an inch or so downwards so as to space these landings rather closer together, and slightly reduce the length of the frame as indicated upon it, an effect which is simply the converse of the stretching action that takes place in the frame when it is being bent. It should be observed that, by constant experience

in such matters, the workmen soon ascertain what is the proper allowance to make.

The batten is now laid out straight on the top of the particular frame bar (keeping their upper ends flush), so that the position of the rivet holes may be indicated by chalk marks across it (Fig. 19, Plate 81). In marking those on the shell flange, a blank space must be left in way of the landings, for the holes here are not punched until the frames are erected. The holes on either side of the landing (if there is only one landing rivet) are not placed symmetrically with it, but with the probable position of the landing rivet, which, as noticed in Art. 519, is placed close to the edge of the overlapping plate (Fig. 23, Plate 92). If the holes in the varying distances between the landings cannot be spaced exactly in accordance with the list, they should be placed closer together—not wider apart. A hole should not be placed exactly opposite the deck marks, for the presence of the deck stringer and beams may interfere with the holding up of the rivets, and similarly with intercostal side stringers, keelsons, and the lower edge of bulb and channel beams having plate knees.

As the transverse flange of the frame bar is a wide one, and the holes are not punched in its centre, their position as regards the toe is indicated by drawing a line upon it (Fig. 19, Plate 81) from end to end of the bar (by means of a gauge and a piece of slate). At the lower part of the bar, where it connects to the floor plate, the holes are reeled, *i.e.* slightly zigzagged (Art. 301), which disposition is indicated by placing the chalk marks on either side of the gauged line, as shown in Fig. 19. In this flange a blank space must be left in way of each beam knee, for these holes are marked subsequently by template; and a blank space should also be left in way of the side stringers, so that the holes for the connecting lugs may be correctly placed later. And, similarly, a blank space should be left in way of the floorhead. The drain holes are also marked, at this time, close to the heel of the bar, in accordance with the 'midship section.

After a number of frames have been marked, the corresponding **reverse bars** are taken in hand. The heel of the reverse bar lies within that of the frame angle; with ordinary frames it is distant the depth of the frame angle, and so, in applying the batten on the scrive board, it is kept this distance within the frame scrive. Starting, as before, from the upper end of the bar (the position of which is indicated on the frame list), the various decks, side stringers, and the floor head are marked, and when the latter point is reached the batten is carried round the upper edge of the floor, as indicated by its scrive line, and the side keelsons and centre line marked upon it. The batten is then laid alongside of the straight reverse bar; the only holes now to be marked are those in its fore-and-aft flange for the bolts for the ceiling planking and sparring,[1] which are spaced (in accordance with the frame list) between the keelsons, side stringers, and decks, the positions of which are marked on the batten. The holes in the other flange for the connecting rivets to the frame are transferred subsequently from the frame angle itself.

The **punching of the bars** is carried on simultaneously with the marking, by another plater, assisted by a number of helpers, small or large, according to the weight of the bars dealt with. Long, heavy bars are supported at the punching machine on trestles having a top friction roller, or on large drums; very heavy bars are suspended from a crane. As no great precision is required in the placing of the holes, the punch may be

[1] The bolt holes for the sparring cleats are generally drilled or beared in the ship, after the sparring is lined in fairly with battens.

worked at a high speed, making 40 or 50 holes per minute. The bars are not cut to length until they are bent.

Art. 487. When a number of **frame bars** are punched, the work of **bending** or **setting** them is taken in hand, this being done by another plater, assisted as before by a number of helpers. The first operation is to bend a *set*, *set-iron*, or *set-bar* to the frame scrive. This is a long, flat bar of soft iron (Fig. 2, Plate 82) about $1\frac{1}{2}$ by $\frac{1}{2}$ inch, more or less according to the scantlings of the frames; it is usually in two lengths, but to simplify the following description it will be assumed to be in one. As the frames are usually erected in the ship from aft forward, the aftermost are the first required, and are, therefore, the first bent; sometimes, however, where expedition is necessary, they are erected from 'midships, working towards both ends, in which case the 'midship frames may be taken in hand first, and those of the two bodies may be bent simultaneously by separate squads, on different slabs.

Suppose now that a frame near 'midships is about to be bent; the first operation is to modify the curvature of the set-iron, which has just been used for the preceding frame. This is done by applying it to the scrive, and where it does not correspond, striking it edgewise with a hammer, a pair of large hammers being held up behind, on either side of the place about to be struck (see Fig. 20, Plate 80), or a single large hammer may be used (as shown by the dotted lines). Finally, when it coincides with the frame scrive, the position of the top of the frame, of the floor head, and of the various bevel lines, or points at which the bevels are lifted, are marked upon it. It is then laid on the bending slabs (as shown at A, Fig. 2, Plate 82), its upper end next the furnace door, and its outline and the various marks are chalked upon them. And then another curve is drawn parallel to the first, by means of a gauge, to represent the toe of the transverse flange of the frame angle (B, Fig. 2). The set is then turned upside down, and its outline again chalked on the slabs, this second mark being for the frame on the other side of the ship.

The set must now be fixed down on the slabs so that it may serve as a pattern or mould round which to bend the bar; but as its curvature is at present that of the outside or heel of the frame, it must be modified to correspond with the inner curve or toe (B, Fig. 2, Plate 82), as chalked on the slabs. After this adjustment, there is another matter to consider before fixing it down, namely, the tendency of an angle bar (or any other bar not symmetrical in cross section) to warp or bend as it cools. If a straight, red-hot angle bar is left alone to cool, it will, when cold, be bent as in Fig. 19, Plate 80. This is due to the fact that the material forming the toes or tips of the flanges cools before the rest, for it is slender and exposed. In cooling it does not freely contract, for it is restrained by the still hot and uncontracting mass elsewhere; and when, subsequently, the latter (the greater bulk of the material) cools, it contracts in a natural manner, being little impeded by the distant toes, and as these, now cold, fail to contract with it, there results a uniform bending of the bar. If, therefore, a frame angle were bent, in the first instance, to its proper shape, the above warping action would cause it to straighten during the cooling and lose some of its curvature, and at the same time cause its middle part to bend upwards from the slabs. The latter deformation may be easily corrected by downward blows from a hammer, and the former may be provided against by the simple expedient of bending it, in the first instance, to a slightly greater curvature. In practice, therefore, after the set has been adjusted to the curve of the toe of the frame angle, it is sprung (*i.e.* bent within the elastic limit) outwards, by fixing its two ends and

pulling it outwards in the middle, a foot or so according to the length of the bar, beyond its normal position (as shown at C, Fig. 2, Plate 82). As the excess of curvature should be uniform from end to end, the pulling or bending force should not all be concentrated at the middle point. In the course of bending the numerous frames, the workmen soon ascertain what is the proper excess of curvature to allow.

The set is then fixed down on the slabs by means of *dogs or hold-fasts*, and its inner edge is backed up against the pressure of the frame bar by pins, round or rectangular, placed in the slab holes in the manner indicated in Fig. 6, Plate 83. Not many holes may be so placed with regard to the set that pins in them will just bear against its edge, in which case L-headed pins are used, or straight pins may be inserted in the nearest holes, and the space between made up with bits of iron, washers, and wedges, of which there is at hand a large quantity of various shapes and sizes; when the holes in the slabs are round, as in Fig. 5, cast-iron perforated discs, circular or cam-shaped, may be used. Where the stiff heel of the frame takes contact with the set, the frame may be bent against pins only, the set-iron not being interposed (Fig. 6, Plate 82).

As shown in Fig. 12, Plate 80, **a dog** is simply an L-shaped bar of round iron, about $1\frac{1}{2}$ inch in diameter, or rather smaller than the slab holes. The two arms, one of which is shorter than the other, meet at an angle about 10 degrees less than a right angle, so that when the short one is inserted in a slab hole, the end of the long one is the first part to take contact with the surface of the slab or with the flange of the frame angle which it is required to clamp down. If now the dog is driven into the hole, the end of the long arm will exert a pressure on the slabs; if driven further and further down, the pressure will increase, the angle between the arms will open, and finally the dog will bend permanently or break. The reason why it is able to exert so powerful a downward clamping pressure without rising out of the hole, is that the friction set up at the two points of contact of its short arm with the sides of the hole in the slab increases with, and is always in excess of, the upward pressure at the end of its long arm. In Fig. 12 any increase of the pressure at A is followed by a similar but greater increase in the two equal horizontal pressures at B and C (the force at A, multiplied by the length of the long arm, is equal to the force at B *or* C multiplied by the thickness of the slab), but the latter two forces each beget a vertical frictional resistance F with the slab, which increases as they increase and is always in excess of the vertical force at A. The clamping pressure at A is, therefore, limited only by the breaking strength of the dog. The dog may be instantaneously released, however tightly driven, by simply striking it a horizontal blow at B, for this causes a momentary dissipation of the frictional resistance at this point. When dogs are unduly forced they bend or break at the elbow, and sometimes, to avoid this, they are made of cast steel, with an enlargement at the elbow, but as elastic bending is essential to a secure grip, such dogs are of little use. Another kind of dog, used by shipwrights for temporarily clamping timber, is shown in Fig. 30 (see also Fig. 14, Plate 97).

While the set is in process of fixing, the frame angle is heating in the furnace, heel up, with its keel end next the door. When at a bright yellow it is pulled out (by a long bar hooked into one of the rivet holes, or by tongs with chain attached), and its end placed without delay against the set and there fixed with dogs and pins. As the bar contracts in cooling (about $\frac{1}{16}$ inch to the foot), its end is kept from 1 to 3 inches beyond the deck mark as chalked on the slabs. The bar is then pulled round

against the set, during which process the toe of the transverse flange, where the curvature is such as to subject it to considerable longitudinal compression, buckles up and requires to be constantly struck down with large hammers. When the curvature is considerable, the bar must be forced round against the set by a tool termed a "*squeezer*;" as shown in Fig. 5, Plate 83, this is a sort of lever having a double, cam-shaped horizontal arm, and a vertical pin B, which, when inserted in a slab hole, forms a fulcrum or pivot.

The bending force of the squeezer may be augmented by bringing crowbars to bear on the horizontal part, using the slab holes as fulcrums. A cold bar bends considerably before its elastic limit is exceeded and a permanent set occurs, and so, in bending such with the squeezer, as each little deformation occurs, crowbars are inserted in the slab holes alongside, to assist it round and hold it until the squeezer is shifted to a more advantageous position; and, in the case of a red-hot bar, a shield of iron may be inserted between it and the squeezer (Fig. 1, Plate 83), to prevent injury to the toe of the flange, when, as in the case of reverse bars, this is on the outside of the curve.

If the frame is amidships it has no **bevel**; in others, if the bevel is not very great, it is **impressed while the bar is still hot, after** the **bending**, as follows. The set-iron is first quickly released from its fastenings, lifted on to the transverse flange, and dogged hard down (see Fig. 23, Plate 80), then the standing flange is bent over by applying a **bevelling lever**, which is passed rapidly from end to end of the bar, in a sort of oscillatory manner, so as to bend the flange over at every point. By a previous study of the bevel board, the workman knows approximately how far over to bend the flange, and he tests and corrects his work by applying bevel squares (which he sets, while the bar is heating, to the angles given on the bevel boards, or as lifted by himself) to the bar, at each of the bevel stations previously chalked on the slabs for the purpose. Imperfections in the bevelling are corrected by hammer blows, after which the bar is released and local irregularities in both flanges faired by the same means. Other remarks on bevelling will be found further on.

The bar being bevelled, it is put aside to cool, but is fixed down with dogs, for when thus secured its vertical warping tendency is checked to a large extent. The set-iron is then turned over and fixed down as before, for the bending of the corresponding frame for the other side of the ship. Having bent the second frame, the first, being cold, is again taken in hand. It is first made to lie flat on the slabs by striking it down with heavy hammers, and then its curvature is tested by applying it to the scrive line as chalked on the slabs. An exact coincidence is not expected, for the bar may have warped more or less than was anticipated; if the divergence is considerable, it may be quickly corrected, as shown in Fig. 5, Plate 83, by placing a pin C at each side of the bar and using the squeezer as shown; and, in the case of a stiff bulb or channel bar, striking it at the same time with a sledge-hammer, as shown in Fig. 1A. If there is a slight deficiency of curvature, it may be corrected by raising the bar a couple of inches from the slabs, and striking the toe of the transverse flange a few swinging blows with a sledge-hammer, as indicated in Fig. 20, Plate 80. If, in an angle bar, there is a slight excess of curvature, it may be corrected by striking downward blows on the horizontal flange near the tip, for, as the material is compressed between the hammer and the slabs by the blows, it expands laterally and bends the bar. In some shipyards a small, portable, hydraulic ram is employed for correcting the curvature of heavy frame bars when cold; it runs on a pair of casters (the flexible hose pipe

for the pressure water being led to it from the roof of the shed, so as not to interfere with its movement), and may be quickly placed against any part of the frame, being backed up by a pin inserted in a hole in the slabs. The use of this powerful and handy contrivance effects a great saving in time and labour, and ensures good work, however stiff and heavy the bars.

Frames which have considerable bevel are **bevelled before bending**, and are reheated for the bending process. A straight bar is bevelled—by hand—as follows. Immediately it is withdrawn from the furnace the ends are dogged loosely down, and the bevelling lever is then applied to the standing flange; as each part of this is successively bent over, the other flange rises from the slabs, as shown in Fig. 22, Plate 80, and is struck down by a succession of quickly delivered blows from four or five hammers. The above procedure tends to curve the flanges, as shown in Fig. 26, instead of bending them over from the throat or heel, as shown in Fig. 27, and this deformation must be corrected, subsequently, by applying a *flattening iron*, as shown in Fig. 26. As the bevel is reduced by this flattening process, it must be made excessive in the first instance. The bevelling is tested as before, by the application of bevel squares, the bevel stations being previously chalked on the slabs; perfect accuracy is not required at this period, for the subsequent bending tends to alter the bevel, and any discrepancies may be made good when the bar is again hot, after the bending. Another way to bevel a straight bar is shown in Fig. 28; the tool A, while being moved gradually along the bar, is struck a series of blows with heavy hammers. The above methods of bevelling are only applicable where the bevel is "open," or obtuse; a "close," "shut," or acute bevel is not so easily impressed. The bevelling lever cannot well be used for a close bevel, because, as its jaw cannot grip the standing flange close to the root, it rounds it over, as shown in Fig. 25, a deformation which, unlike that which occurs with an open bevel, is not easily remedied by the flattening iron. For this reason, a close bevel is usually impressed simply by hammering the flange, numerous blows being struck close to the heel of the bar, as shown in Fig. 29.

Most yards are equipped with a **bevelling machine**. It runs on rails, and, when a bar is about to be bevelled, is pushed in front of the furnace door, so that the bar, passing between its rollers, is drawn out of the furnace, and, at the same time, bevelled to any degree. The action of the machine is shown by the diagram, Figs. 4 and 5, Plate 80. The roller R revolves by steam or electric power; the three mitred discs above it run loosely. The central disc A may be inclined to the right or left (by means of the hand wheel B), and as, in making this movement, it is constrained to pivot about its lowest point, it bends the flange over from the throat, without curving it. The inclination of this disc is indicated automatically by the pointer C. The bevels supplied to the men, in the case of machine bevelling, are given in degrees, and are lifted by the loftsman (or by the frame-bender himself) at every 4 feet in the length of each frame. When a bar is about to be bevelled, the workman ticks off its particular bevels, or angles, with chalk on the bevel indicator D, marking them 1, 2, 3, etc. The bevel marked 1 is that required at the end of the frame, No. 2 is that required 4 feet from the end, No. 3, 8 feet from the end, and so on. As the bar enters and passes through the machine, the man who works the hand-wheel B must observe that when the end of the bar enters the machine he has the pointer C at No. 1 bevel, and that during the next 4 feet of travel of the bar he has caused it to move gradually to No. 2 bevel. He does not require, however, to watch the progress of the bar itself, for this is conveniently shown by the

clock-faced indicator E. These machines can also bevel Z and bulb-angle bars. After passing through the machine, a bar is still sufficiently hot for the bending process; one 40 feet long, for instance, may be bevelled in little more than a minute. If bevelled by hand, before bending, it requires to be reheated. The machine thus saves both time and labour; and it does its work well, for whether the bevel be close or open, it bends the flange over from the throat, and leaves it fair and regular, conditions scarcely attainable with hand work. It should be observed that if the bar is very hot and soft, the pressure of the feeding roller, if too great, tends to lengthen it and throw out the landings and rivet holes.

When impressing a considerable bevel on the frame bars, it is not practicable to bend both the flanges over precisely from the heel, the material here being an unyielding mass (see Fig. 8, Plate 6). Now, while a hollow in the transverse flange (B and D, Fig. 8) is unimportant, it is very objectionable in the shell flange (C and E, Fig. 8), owing to the impossibility of securing close contact with the shell plating, and, in view of this, it should be endeavoured so to bevel the bars that the irregularity shall be in the transverse flange (B and D, Fig. 8). This effect is, of course, also found with machine bevelling (when excessive), and it is particularly marked with heavy bars of bulb-angle section. In practice, when the hollow in the shell flange is pronounced, as at C and E, Fig. 8, the sharp ridge formed by the heel of the frame is usually chipped off.

After the two frame angles are bent, the corresponding pair of **reverse bars** may be taken in hand. The first operation is to chalk their outline on the slabs. As regards the upper part this is already done, for the outline here is the same as that of the frame angle. The outline of the floor portion is found on the scrive board, and, having bent a short set-iron to this, and marked thereon the floor head and centre line, it is laid on the slabs in its proper position with regard to the frame curve (as ascertained by the floor head marks, and its known height above the frame at the centre line) and chalked in. The complete outline of the reverse bar is thus chalked on the slabs, but in view of the warping action which accompanies the cooling, the bar is not bent precisely to this line. Contrary to what occurs in the frame angle, the curvature of a reverse bar increases during the cooling, for its heel is on the inside of the curve. Here, therefore, when fixing down the set (which is usually in two pieces, one for the frame and one for the floor portion), its ends are drawn slightly outwards. The procedure in bending the bars is similar to that just described for the frames, the bevelling being the same, except in way of the floor plate, where there is no bevel. As the standing flange of the reverse bar is on the inner edge of the curve, it may be bent round pins alone, without the interposition of a set-iron. The men are sometimes careless in bevelling the reverse bars, for as only the side stringers and lower-deck gunwale bar are attached to the fore-and-aft flange, inaccuracies are not so noticeable.

After the reverse bar is bent and bevelled, its curvature is tested by applying it to its outline as chalked on the slabs. If of light scantlings compared with the frame angle, then, so long as it is fair, perfect coincidence is not required, for the stiff frame bar will pull it into place, and even if this, in so doing, should itself bend slightly, as a whole, it will be pulled or pushed into shape by the beams and stringers. Its curvature at this time should, indeed, be less than that finally required, for the subsequent punching of the rivet holes in its transverse flange tends to increase it. This is due to the fact that as the punch forces its way through the flange, some of its intense compressive force is diverted laterally, which

circumstance, by stretching the flange, results in a bending of the bar; at each hole the effect is very slight, but as there are a large number, the total effect throughout the length of the bar may become quite marked. It is more pronounced in bars of light scantlings, and when the holes are of large diameter and are punched near the toe, if situated on the neutral axis, there would, of course, be no bending tendency.

Floor plates of shallow type are bent simultaneously with the frames, by another set of workmen. The back end of the long, narrow, frame furnace is sometimes enlarged to serve as a plate-heating furnace, a small slab floor being provided in front of it. The shape of a floor plate before, during, and after bending is shown in Fig. 1, Plate 82. The 'midship floors are in two pieces, and, in the case under consideration, they are lap-jointed on either side of the centre line. Only the narrow end is bent, and, the more readily to bend its extreme end, where sharply curved, the surplus breadth at this part is first sheared off. A massive set-iron (about 3 by $\frac{5}{8}$ inch) is then bent to the upper edge (as scrived on the scrive board), and, the floor head being chalked upon it, it is fixed down on the slabs. The same set usually serves without modification for a large number of floors. Only as much of the narrow end as it is required to bend is heated, and when at a bright yellow heat the plate is withdrawn by a chain, attached by a clamp to its butt end. Its head is then fixed against the set, as shown in Fig. 1, and its butt end pulled round by the chain. For this work, a small winch is employed, because, to bend a plate edgewise, requires considerable force. During the bending, the inner edge constantly buckles up, whereupon the bending is stopped, momentarily, until it is beaten down. It is important that the edge should be pulled everywhere close against the set, for if not it must afterwards be sheared to shape, and this is an awkward thing to do, for a curved shear knife must be used, which, while fitting one part of the curve, does not fit another.

Art. 488. The next frame-making operation is to **adjust and try together** the three parts, the **frame angle, reverse bar, and floor,** so that they may be bolted together ready for riveting. This work may be started as soon as a few frames and floors are bent. It is conducted on the scrive board by another set of workmen. The first operation is to test the curvature of the **frame angle** with its scrive. Perfect coincidence is not expected, for so far it has only been checked by applying the bar to a rough chalk line on the slabs; discrepancies are now corrected by hammer blows, as already described, and afterwards the bar is laid to the scrive and the following marks transferred to it. As the bar has always some surplus length at the keel, the centre line is marked across it, and if its upper end extends above the deck line, it also is marked for cutting, about 1 inch below the beam line. Then the plate landings are marked, also the lower decks, side stringers, ribband lines, and a horizontal water line situated, say, 8 feet above the base line, all marks being nicked in by a cold chisel, and different ones distinctively. The rivet holes for the beam knees are marked by a pattern template, as shown in Fig. 16, Plate 81. It is important that this template should be accurately applied, for as two of the holes in the beam knee are also marked from it, any inaccuracy would spoil their coincidence. Its top is cut with a radius, so that whatever the angle of incidence of the beam line and frame, it may just touch the former. As the beams near amidships are all about the same height, it is not possible to indicate all of them clearly on the scrive board, and so, for these, the loftsman supplies the men with a short batten, on which are marked the proper heights of the beams from some convenient level line. The three holes which have been

omitted in the transverse flange for the connecting lugs of the side stringers are now marked, by a little template, from which the lugs also may be marked (Fig. 16). If, on account of a sharply curved bilge, some holes have been omitted at this part, they are now marked for punching; and if any have been omitted at the lower end, in way of the heel piece, or at the floor head or its lap joint (the latter being at a known distance from the centre line), they are now marked. The rivet holes for the beam knees and keelson lugs are distinguished by a paint mark, to indicate to the riveters that they are not to be riveted up with the others. When all these marks are made the ends of the bar are cut, and the additional holes punched.

The corresponding frame angle for the other side of the ship is now taken in hand; there is no scrive to adjust it to, but its curvature is quickly checked and the various holes, etc., marked, by using the first frame as a pattern, for which purpose it is turned upside down and the first laid on the top.

Having prepared the two frame angles, the **floor plate** is next taken in hand, but here some preliminary work is required. Only half of its upper edge is scrived on the board, and the other half must now be drawn in with chalk, by means of a set-iron, bent to the scrived-in half. As shown in Figs. 16 and 14, Plate 81, this set also serves as a template for marking the rivet holes in the floor and the corresponding ones in the reverse bar. It is only half as broad as the flange of the reverse bar, so that the holes are half off and half on its edge; this is advantageous in that it facilitates the marking of the holes and the bending of the set-iron. When bending it to the scrive, it should be so adjusted that its holes may fall symmetrically with the centre line, and, having chalked upon it the position of the floor head and side keelsons, it is turned over and placed in the same relative position on the other side of the centre line (as determined by height measurements), and its outline and marks chalked on the boards. The two halves of the floor plate are now laid in position (see Fig. 16), the one overlapping the other and with their upper edges coincident with the scrive mark, or, if anything, rather below it, and the following lines struck in (with chalk-line) upon them: the centre line, base line, rise-of-floor line, a line coincident with the straight part of the top of the floor, a vertical line through each side keelson, and a level line, say 12 or 18 inches up from the base line.

The two frame angles are then laid in place on the top of the floor, with their lower parts coincident with the rise-of-floor line as just chalked (Fig. 16, Plate 81), the upper part of the one being adjusted to its scrive mark, and that of the other to short half-breadth marks specially made on the scrive board for the purpose. The heel of the frame angle is then chalked on the floor plate, and the rivet and drain holes marked through. The set-iron for the reverse bar is now laid in place (Fig. 16) on the upper edge of the floor (its position, if the floor overlaps the scrive, being ascertained by gauge marks), its upper edge is chalked in, if the floor extends above it at any part, and its holes are marked through. If holes do not fall conveniently in way of the lugs for the side keelsons, special ones are now marked on both the floor and set-iron (Fig. 16). The outer end of the set overlaps the frame angle, and any holes there may be in this overlapping part are marked through on the frame, so that they may act subsequently as guide marks when the set is similarly placed for marking the reverse bar (Figs. 14 and 16). The set is then turned over and applied in the same way to the other half of the floor.

The holes in the lap joint of the two floor plates may be marked by the special template shown in Fig. 17, Plate 81. When this is placed in

position on the overlapping plate (Fig. 17), the guide arms extend over the lower one, and when all the holes are marked—including those in the guide arms—and the overlapping plate is removed, it may be replaced subsequently (by means of the guide holes) in exactly the same position for marking the holes in the lower plate (Fig. 18). Sometimes the holes are punched in the overlapping plate before it is laid in place, but this usually involves extra labour. The holes in the frame and reverse bar which fall on the lap may be transferred to the lower plate when the upper one is removed, by the frame angle, still in position, and the reverse bar set-iron. Limber holes are marked on the floor plate, in accordance with the 'midship section. The level line is permanently marked with a centre punch, and the dabs encircled with paint; these marks are useful in checking the relative positions of the two floor plates when riveting them together, for checking the vertical position of the heel pieces, and for roughly plumbing the frames during erection.

The **reverse bars** are now taken in hand. So far the only holes punched in them are those in the fore-and-aft flange for the ceiling bolts, and now the rivet holes in the other flange, for the connection to the floor plate and frame angle, which have already been punched in the latter, must be transferred. For this purpose the reverse bar is turned upside down, and the frame angle laid on top of it, as shown in Fig. 14, Plate 81. The two bars must be so placed that their lower parts, where they diverge, are in their proper relative positions, for if not they would not both conform with the floor plate, in which the rivet holes are already marked. This might be accomplished by actually trying the floor plate in place between them, but the same result may be more conveniently secured by means of the floor set-iron, which, in effect, is equivalent to a strip of the upper edge of the floor. When this is applied to the reverse bar, as shown in Fig. 14, with its end overlapping the frame angle (as it did before when the floor was marked), then, when the latter is so adjusted lengthwise, that the guide holes, previously marked upon it from the set, are again coincident with the same holes in the set, the two bars must necessarily be in their proper relative positions, *i.e.* the holes in both of them (so far only indicated on the reverse bar by the set) will correspond with those already marked on the floor plate.

To complete the marking of the reverse bar, its upper and lower ends are marked for cutting, the latter at the centre line as indicated on the set (Fig. 14, Plate 81), and the former flush with the top of the frame angle, or, if it stops at a lower deck, rather more than the height of the continuous gunwale bar above it. Then the positions of the keelsons and side stringers are nicked in, the former from the marks on the set, and the latter from those on the frame angle; and a rivet hole is marked on the fore-and-aft flange on each side of these nicks for the connection of the fore-and-aft keelson angles. Unless the work is carefully done, however, it is preferable to bear these two holes in the ship, after the keelsons are lined off (Art. 512). If special holes have been punched in the floor for the keelson lugs, their position is shown on the set-iron, and they are now transferred to the reverse bar (Fig. 14). A rivet hole may also be marked on the fore-and-aft flange just above the lower deck, to take the continuous gunwale bar, but it is better to bear this hole in the ship after the deck beams are faired. The curvature of the reverse bar may not be quite that of the frame angle, and when the latter is placed upon the reverse bar to transfer the holes, it must be carefully adjusted successively at each part, so that its toe may be flush with the heel of the reverse frame, or, in the case of deep frames, at a fixed parallel distance therefrom, as indicated by a line previously gauged

on the reverse bar. If, at the floor head, a blank space has not been left in the transverse flange of the frame angle, one of its rivet holes may fall half on and half off the toe of the former, in which case it is better not to punch it, but to introduce another; this ill-placed hole is a common feature in ships' frames.

The reverse bar and floor plate may now be cut and punched. It should be observed that the holes in the upper edge of the floor are not marked on the faying surface, and if the utmost efficiency in the riveting were required, they would have to be reversed to the other side of the plate. But although the rule of punching from the faying surface is strictly observed, an exception is generally made of these particular rivets in the floors. As the lower curved edge of the floor plate—as chalked from the frame angle—is on the faying surface, it should be reversed, so that the plate may be sheared from the other side *to* the faying surface (Art. 323). This may be readily done by punching a few consecutive holes (at the same time as the others) from the edge of the plate to the line, so that when the plate is turned over, the ends of the scores, so formed, may locate the curve and enable it to be struck in with a chalk-line (in short lengths), or with a flexible batten. The scoring of the plate in this way is also advantageous in that it causes the shearing to fall off in short pieces, if in one long piece it would interfere with the adjustment of the plate at the machine. The edge is sheared from $\frac{1}{4}$ to $\frac{1}{2}$ inch within the frame line, so as to leave ample clearance from the shell plating.

The **frame heel pieces** are usually fitted when the frames are screwed up ready for riveting. In a vessel having a large rise of floor, they have a sharp bend in the middle (Plate 101), and in such case they are made by "angle smiths." The position of each one, when put in place on the frame to mark the holes, should be checked by gauging from the level line nicked in on the floor for the purpose. It would be improper to adjust it merely flush with the shell flange of the frame angles, for, as the latter are not always fair at their ends, the heel piece might not lie on the top of the keel, or it might be too low, and thus, by elevating the entire frame, destroy the fairness of the vessel's bottom and deck beams. Sometimes the heel pieces are made at an early period, so that they may be fitted on the scrive board. The keelson and side-stringer lugs are also fitted when the frames are screwed up ready for riveting. The position of each keelson and side stringer is indicated by a nick on the reverse bar, and the lugs should be fitted symmetrically with these; but if three holes have not been specially punched, this may be impracticable, for in taking the three nearest holes, the lugs may project more on one side than on the other, and be unnecessarily long. If the three rivet holes in the frame have been punched by a pattern template, the same template may be employed for marking the lugs. Lugs towards the vessel's ends, which are much bevelled, should be fitted and marked in place, otherwise they are very apt to be out of line with the reverse bar, both in bevel and level (see Fig. 7, Plate 80). This is a common defect, and it is often due to the fact that keelson lugs and the like are fitted by lads. It is often clumsily remedied by fitting liners at the back of the keelson or stringer angles (Fig. 10), but sometimes it is not remedied at all, in which case the only contact secured is that due to the distortion of the flanges during the riveting (see Figs. 8 and 9).

Art. 489. In **bending frames** at the bow or stern which have a **double curvature**, two set-irons are required, one for the lower part and one for the upper. In fixing them to the slabs (only that set which takes the toe of the bar need be fixed down), one is so placed as to

take the heel of the bar and the other the toe, and when the bar (already bevelled) is withdrawn from the furnace, it is placed in the gap between the two sets, and both ends bent round simultaneously. Fig. 6, Plate 82, illustrates the manner of bending bossed frames; here the bar is bent in detail, being reheated as required. When there is only a small reverse curvature, as shown in Fig. 7, the hot bar may be forced into the hollow of the set by blows from a massive ramming tool, slid forcibly against it over the surface of the slabs.

The **bulkhead frame, or shell angles,** are bent with the other frames. In the case of the end bulkheads, one of the bars (if there are two) has a close, and the other an open bevel (Fig. 6, Plate 80). In the former the holes in both flanges are punched before bending and bevelling, those in its transverse flange being transferred to the other when both are bent. The holes are punched in the close-bevelled bar before it is bent and bevelled, because, owing to the bevel, it would be awkward, if not impracticable, to do so afterwards. When marking the holes in the transverse flange of the straight bulkhead bar, a space should be left in way of those decks and side stringers which pierce the bulkhead, so that suitable holes may be punched subsequently for the watertight collar angles (Figs. 11 and 12, Plate 55). In transferring the holes from the one bar to the other, the one is placed on the top of the other, and, if there is any bevel, it is important that they should be kept apart by the thickness of the bulkhead plating, and with their shell flanges in one plane; if placed in contact, then, when riveted to the bulkhead, the one flange would project beyond the other, as shown in Fig. 6, Plate 80. This also applies to the marking of the double frame angles required at the fore end of vessels of full form (Art. 108). For caulking purposes, both toes of the open-bevelled, bulkhead, frame angles should be planed before bending, otherwise they must be chipped by hand.

Art. 490. Channel frames are bent in a similar way to angle frames. They do not alter curvature in cooling, which simplifies the work; they warp vertically, but this, of course, may be easily corrected. As they combine in themselves frame angle and reverse bar, they are stiff to bend; and care must, therefore, be taken to bend them to their exact shape in the first instance. If, when cold, they do not correspond with the scrive, they cannot, as with angle frames, be corrected by hammer blows: if there is a beam-bending machine at hand they may be bent by it, or the rail-straightener shown in Fig. 2, Plate 83, may be used; otherwise, they may be bent on the slabs, by dogging them down and applying the squeezer as already described; the hydraulic squeezer, described in Art. 487, is, of course, particularly efficient for heavy work of this kind. The tendency of the rivet holes in the shell flange at the bilge to become oval with the bending is here exceedingly marked, due to the fact that in a channel bar the neutral axis is midway between the two flanges, and not close to the shell flange as in an angle bar. In practice, therefore, even when the curvature at the bilge is very easy, the punching of the rivet holes must be deferred until after the bending.

It is not every punching machine that can deal with channel bars, for the bolster must admit of the lower flange occupying a position directly under the one in process of punching; one especially adapted for this work is shown in Fig. 12, Plate 115. Bevelling machines are not adapted for channel bars, they must, therefore, be bevelled by hand, but the angle of bevel is usually small, for the bow and stern frames, where alone it is considerable, are usually of built type. If the bevel is considerable, they are bevelled (in one or both flanges) before bending, for as there are two

flanges to manipulate, it might not be practicable to do so after the bending. The mode of procedure is illustrated in Fig. 24, Plate 80. On withdrawing the hot channel bar from the furnace, a heavy rectangular bar is laid on the web and clamped rigidly down with dogs, whereupon both flanges are bevelled simultaneously, by different workmen, in the manner already described. If the bevel is considerable, the clamping effect of the rectangular bar does not entirely prevent the web from rising under the action of the bevelling lever and becoming distorted as shown in Fig. 24; it requires, therefore, to be faired subsequently, with the flattening iron (as in Fig. 26).

When a channel frame is split in way of the floor plate, as shown in Figs. 1, 3, or 4, Plate 6, the following is the procedure adopted in bending it. Two set-irons are used, a long one for the part above the bilge and the split reverse-bar portion, and a short one for the split frame portion. When both sets are fixed in their proper relative positions on the slabs, the smaller one is temporarily removed, and, with its dogs, etc., laid carefully aside, so that it may be expeditiously replaced. The channel bar, the lower end of which has already been split (Art. 533), is now withdrawn from the furnace, and the part of it at the termination of the split, being placed against the set, the upper and split reverse-bar portion are simultaneously bent; as soon as the latter part is bent out of the way, the small set is replaced and the split frame portion bent round it. After this, while the bar is still hot, it is bevelled, both flanges simultaneously; or if already bevelled, the existing bevel is adjusted (as already noticed, if the bevel is considerable it may be necessary to impress it in a first heat, when the bar is straight).

In bending **Z frames**, a special procedure must be adopted, because they do not lie flat on the slabs. As in the case of channel frames, their curvature does not alter while they cool, and the holes at the bilge are subject to the same pronounced ovalling effect. Bevelling machines are adapted for Z bars (Fig. 4, Plate 80), but as they only bevel one flange at a time, the bar must be passed through twice, and be re-heated for bending. When bevelled by hand, before bending, the bar is dogged down, as shown in Fig. 21, with its web resting on a long bar of iron; or the lower flange may be inserted in a long crevice left purposely between the slabs, so that its web may rest on their surface. Only one flange can be dealt with at a time, and the bar must be reheated for bevelling the other. There are different methods in vogue of bending Z bars. By that shown in Fig. 5, Plate 83, a broad and massive set-iron is used; it is bent to the scrive, edge up, so that when similarly placed on the slabs it may stand sufficiently high to take the heel of the Z bar as shown. As the pressure of the latter tends to bend the set laterally, it must be thick, and be substantially made up behind. To support the web during the bending, a number of rectangular iron blocks are placed loosely in front of the set. The lower part of the squeezer must stand above the slabs, so as to take contact with the heel of the Z bar, a condition secured by forming its fulcrum pin with a shoulder as shown in the elevation (Fig. 5). The method usually adopted in bending heavy Z bars, is shown in Fig. 4, Plate 82, and in Fig. 6, Plate 83. The cast-iron blocks B (Fig. 6) not only support the web of the bar, but their shoulder takes contact with the heel. It is not necessary that the outer end of the blocks should take contact with the shell flange of the Z; it is advantageous, however, that it should do so in the case of the unbevelled 'midship frames, because the ends of the blocks then check the tendency of the shell flange to fold inwards at the bilge, where the curvature is sharp. To secure this

advantage, therefore, the blocks are usually made with double ends, suitable for bars of different sizes. The method of bending a Z bar when split at the bilge is shown in Figs. 3, 4, and 5, Plate 82. In this respect they are more easily manipulated than a channel bar, because, as the split reverse-bar and frame portions stand at different levels, a set for each one may be fixed down permanently, as shown in Fig. 4. To fair and adjust Z frames on the scrive board, is awkward, for they do not lie flat, and as the heel is elevated about 3 inches above the scrive, its coincidence therewith must be ascertained by means of gauges, as shown at C, Fig. 6, Plate 83.

Bulb-angle frames are bent in the same way as angle frames, a thicker set being required to take contact with the bulb. Like channel and Z frames, they are stiff to bend, and the holes in the flange at the bilge are subject to the same pronounced ovalling tendency. According to the relative massiveness of the bulb and heel, their curvature during the cooling may alter in either direction, or it may not alter at all.

CHAPTER XXXIV.

Art. 491. The various parts of the hull are not tried in place until they are shaped and finished. To put each one in its berth, in order to mark its outline and rivet holes, and then take it away, and, after shaping and punching it, bring it back, would involve much labour and loss of time. It should be observed that in the early days of iron shipbuilding, when expedition and economy were less considered, this was a common plan. The independent preparation of the various parts is accomplished by means of **templates.** Of these there are two distinct kinds, those which serve merely for transferring the holes and outline of one part (or parts), already punched, to another, and those which serve as patterns for marking both parts, independently. Any flat piece of wood (or metal) on which the position of the holes, in a part already punched, may be marked for transference to a conjoined part, about to be punched, may be termed a "*transferring template.*" If the holes are bored in it, so that both parts may be marked from it, it is a "*pattern template.*" The former is the more largely used, and will be noticed first in the following.

A **template** such as is used **for the shell plates** is shown in Figs. 3 and 8, Plate 91. It is simply a skeleton mould, made of pine battens, about $\frac{1}{4}$ inch thick, tacked together. It must, of course, be sufficiently strong not to rack and alter shape should it by chance be roughly handled; it might be made amply strong in this respect by fitting a diagonal stay across the various parallel members, but as this would be somewhat in the way, it is usually preferred to secure the necessary strength by substantial tacking of the joints. The platers generally make their own templates, but where, as in the shell plating, one may serve for marking a large number of plates, it may be neatly made in the joiners' shop.

In proceeding **to mark a plate for cutting and punching**, the template is first fixed in the berth it is to occupy (by *clips* or *hutch hooks*), in such a way that all the rivet holes in the frames, etc., are covered by it (see Fig. 8, Plate 91). The holes are then marked on its inner surface by a *marking pin* or *marker.* This is simply a hollow cylinder or tube of metal, the end of which, being dipped in whiting, leaves a circular impress on the template. It is important that the diameter of the marking pin should be just that of the rivet holes through which it is thrust, for, if smaller, its mark would not often be concentric with the holes. Some of the holes may be transferred to the template by striking the latter with a flat-faced hammer against the steel work, so that the soft wood may take an impression of the holes. This method is advantageous in that it indicates very precisely the size and position of the holes, the circle of whiting left by a marking pin being more or less blurred and imperfectly concentric with the hole; it is particularly useful where, through inaccessibility, it may be difficult or impossible to use a marking pin.

The outline of the template need not be precisely that of the finished plate; that is to say, its marginal battens may extend beyond, or fall

within, the edges of the plate, as indicated in its berth. Preferably, they should fall rather within, for then their position may be taken account of by **spilings**, *i.e.* by noting in figures, at various points on the margin of the template, how far off from its edge is the position of the edge of the plate at these points (Fig. 8, Plate 91). If the template were the precise shape of the plate, there would, of course, be no need to take spilings, but to make an accurately shaped template for each plate would be tedious, especially if its edges were curved; by the usual method, the same one may serve for a large number of plates, and, with slight modification, for many more. If the edges of the template are straight, and if the plate has a straight edge, then, of course, one edge of the template may be placed coincident with the straight edge of the plate (Figs. 3 and 8).

If the position of the edge of the plate is indicated (at its berth) by a line, as at B, Fig. 8, Plate 91, and the template extends beyond it, it may be transferred to the template by thickening it at points with chalk (as shown), and striking the template against it at these places. Or gauge marks (or a gauge line) may be made, previously, at a fixed distance from the line, so that by their means its position, when covered by the template, may be determined and marked upon it (see Fig. 8). If the plate makes an edge-to-edge, or butt joint with another already in place, then, if the template overlaps the edge of the plate, this may be pencilled directly upon it. If it falls short of the edge, spilings may be taken; but, if accuracy is required, tongues of wood are usually tacked upon the template, with their ends either butting against or overlapping the edge of the plate, as at C, Fig. 8.

To mark the plate from the template the latter is laid upon it with its marks uppermost (Fig. 3, Plate 91). If one edge of the finished plate is straight, and the rough plate happens to have a straight edge, the necessity to shear it again may be avoided by disposing the template from it as a basis (Fig. 3). And, similarly, it may be possible to avoid the shearing of one of the ends. If the edges of the finished plate require to be planed, then the template must be so disposed as to leave a margin of at least $\frac{1}{8}$ inch. The edges are transferred by setting off the spilings noted on the template, but if their position is marked on the latter, they are transferred to the plate below by striking a fine centre-punch right through the template at the marks (Fig. 3). Subsequently, when the template is removed, a chalk line is struck through these spiling marks, or centre-punch dabs (Fig. 2); if the edge is slightly curved, the chalk line may be struck sideways, or in short lengths; but if the curvature is considerable, a flexible batten must be employed. Edges which are to be planed are marked permanently by a centre-punch; and for this purpose the plater sometimes employs a double punch, which makes a second dab about 1 inch within the line, for by this means he is able to check the work of the planer in case the latter should spoil the plate by planing more off the edge than is required.

As regards the transference of the holes, some, it may be necessary to mark on the upper surface of the plate and some, on the lower, depending on which is the faying surface for these particular holes. In the case of an inside strake of shell, for instance, the faying surface for the frame rivets is the inside of the plate, and that for the landing rivets, the outside, and, consequently, these two sets of holes must be punched from opposite sides (Art. 306). They are transferred by the double-arm **markers**, or **reversers**, shown in Figs. 4 to 7, Plate 91. The reverser, Fig. 5, is employed for marking holes on the under surface; when using it, the plate is laid on trestles, and each time the hole in the end of the upper arm is adjusted over a hole on the template, a boy below the plate marks the hole

in the lower arm with a marking pin. The reverser, Fig. 4, is not often used, for it is awkward to manipulate, and it is always uncertain whether or not it is marking the holes properly. The reverser, Fig. 6, is used for transferring the holes to the upper surface of the plate. When using it, the template is lifted locally so that the lower arm may be slipped in between it and the plate; the template must, of course, be firmly clipped to the plate elsewhere, so that the lifting of it at one part may not shift it as a whole. With small templates, which cannot be lifted locally without danger of shifting them bodily, the holes are marked by driving a centre-punch through their centres, and when the template is removed, making a circular mark around each dab with a marking pin. By this method the accuracy of the work depends on the care and skill of the men, for in driving the punch through the template, the centre of the hole is merely judged by the eye, and, again, when applying the marker concentric with the dab; there are thus two chances of error, and if both happen to have the same bias, the resulting discrepancy may be large. With skilful workmen, however, holes transferred in this way may be no less accurately placed than when a reverser is used; for with the latter there is also a chance of error, because its marks may not always be perfectly coincident with the marks on the template, and they may be ill defined and imperfectly circular. Whiting is used for marking the holes on the templates, for it may be washed off when another plate is about to be marked. Paint is used for marking plates, etc., because it is not so easily effaced, it does not wash off in wet weather, and it serves to lubricate the punch.

Art. 492. Pattern templates differ from the transferring templates just described, in that they are carefully made patterns, in which all the rivet holes are *bored*, and from which the conjoined parts may be prepared quite independently. They are only applicable, however, for parts which occur in large numbers, and which are identical in one or more features, for it would obviously be unprofitable to make a pattern which could only be used once or twice, the labour of making it being greater than that saved by its application.

A simple example will illustrate their use. In Fig. 3, Plate 84, the short angles B, connecting the floor plates to the vertical keel, occur in large numbers, and are identical in every respect. If the vessel were built in the old-fashioned, unsystematic way, the holes in the ends of the floors and in the vertical keel would be punched arbitrarily, and when a number of floors were erected, they would be carefully faired by the shipwrights, and temporarily secured (by ribbands, shores, and clamp washers) until the connecting angles were prepared, this being done by means of transferring templates, or by applying the angles themselves in place. By the procedure now generally adopted, pattern templates (A and B, Fig. 4) are made at an early period, one for each flange of the connecting angle, from which the holes in the floor plates, vertical keel, and in the angles themselves, may all be marked and punched. The connecting angles may, therefore, be made at any time, and they may be riveted to the floors (or to the vertical keel) before these are erected, so that immediately they are erected they may be bolted in their proper positions, thus saving time and avoiding the labour of fairing the various parts and making temporary connections. A separate template is usually made for each flange of the angles, because, if the same one were used for both, the holes would be opposite one another, a disposition which, in small angles, it is usually endeavoured to avoid, to facilitate the riveting and avoid lines of marked transverse weakness in the bar.

It is now common to prepare nearly all the framework of a cellular

double bottom by pattern templates, as also many other parts of the hull. The system is sometimes referred to as "**double templating,**" because the template serves for marking the holes in *both* connected parts, instead of in one only. It is advantageous in that it results in great expedition and minimizes labour; for all parts may be made independently, and, therefore, without delay, and many may be riveted together by hand or hydraulic power before they are erected, or before even the keel is laid. It is also advantageous in that, as the templates are prepared in the mould loft, the most suitable disposition of the conjoined parts and of the connecting rivets may be carefully determined, and thus leave nothing to the uncertain judgment of individual workmen. But, on the other hand, it demands great care on the part of the men, for a small mistake in applying the templates may result in numerous bad holes and ill-fitting or spoiled parts. The chance of serious error is greater than in the single-template system, because, not only is there a chance of the pattern template being placed, say, a shade too high in the one part, and a shade too low in the other, but there is also a possibility of some of the holes being punched a shade above the mark in the first, and a shade below it in the second, an accumulation of four errors which might result in a serious discrepancy. But, with single templating, there is also a considerable chance of error, for, besides deviations of the punch, inaccuracies may occur in marking the holes on the template, and again in transferring them from this to the plate or bar, for as the marking pin is always at least $\frac{1}{16}$ inch smaller than the hole through which it is thrust, its impress may not be concentric with it, and may be so ill-defined as to offer but a poor mark for the punch. With a pattern template the marking work is more accurate, because the holes in the template are cylindrical, and the marker is made to fit them with plug-like accuracy, and further, throughout the whole of the work the parts are conveniently placed, in the shed. In yards where the double-template system is largely adopted, it is found that when the men exercise due care the work is no less accurate than when done by the single-template system.

Before describing the procedure of preparing the parts of a cellular double bottom by pattern template, it will be well to notice a point of fundamental importance in this system of work. In the example just given of the angle bars connecting the floors to the vertical keel, it is evident that in the four applications of the two templates (to the floor, vertical keel, and each of the two flanges of the angle bar) they must be disposed in the relative positions they were designed to occupy when made in the mould loft, for, if not, the floor plate when connected to the vertical keel would not occupy its proper position, it might be too high or too low. If, when the two templates were made, their lower ends were cut flush with, say, the top of the keel, and if, each time they were applied to the structural parts, their ends were again kept flush with the top of the keel (or with its known position), the required result would, of course, be secured. The keel, however, cannot be taken as a basis, for its position could not be indicated on all of the parts; what is done, therefore, is to assume a **level line,** about halfway up the floors, say, 2 feet above the top of the keel, mark it on all the structural parts, and on all the pattern templates, and use it as a common basis in applying the latter. This level line is lettered LL in the various parts shown in Figs. 3, 4, 7, and 8, Plate 84. For instance, when the first of the two templates (A or B, Fig. 4) for the vertical connecting angles is applied to mark the holes in one of the flanges, a mark is made on the heel of the bar opposite a mark or nick, LL, on the template, which serves as a guide when applying the other template to

the other flange. Also, when applying the same templates to the vertical keel and floor, their guide marks are kept coincident with the level line drawn on these parts (see D, Fig. 4, Plate 85). In some cases the two templates are united as shown at Q, Fig. 4, Plate 84, so that both flanges of the angle bar may be marked by one application, but unless the angle bar is perfectly straight this method leads to inaccuracies.

Art. 493. Notice now the procedure of **preparing the framework of a cellular double bottom** such as that shown in Fig. 3, Plate 84. It should be observed that in few shipyards is the work carried out in precisely the same way; in the following an excellent and fairly common method will be described. The scrive board for a vessel having a double bottom is shown in Plate 79. In large, full-lined, cargo boats quite one-third of the double bottom frames amidships are identical, so that these may be made entirely by template, without any reference to the scrive board. The various templates provided for the work are shown in Fig. 4, Plate 84.

Notice, in the first place, the preparation of the frame **angles**. For those amidships there are two templates, C and D (Fig. 4, Plate 84). Template C is for the vertical or floor flange; it is a duplicate of the lower part of the floor template, and it not only gives the rivet and drain holes, but the curve of the bar. Template D is for the shell flange; it gives the rivet holes and shell landings, and it will be observed that there is a hole in each landing, for in way of these frames the landings are parallel to the keel, and there is no uncertainty as to the ultimate position of the frames (Art. 486). By means of these two templates the frame angles may be bent, cut, and punched. If the bars, as delivered in the shipyard, are free from twist, they might be bent to shape cold, in the beam-bending machine, for they are short, of light scantlings, and almost straight. But it is usually found easier and more satisfactory to bend them in the usual way, on the slabs, for they may then be finished flat and fair, and as the one set-iron serves for all the bars, the work may be done expeditiously, in wholesale fashion. Sometimes the necessity to bend these frames is avoided by placing the tank margin plate so far in from the bilge as to include within the tank only that portion of them which is straight (Fig. 14, Plate 17, and Plate 111). The holes, etc., are marked after the bars are bent, by means of the templates; and, in applying these, they must be placed in a certain lengthwise position relatively to one another, for, if not, the shell landings would not be at the proper distance from the keel. Their proper relative position is, of course, fixed by the loftsman who makes them, and is indicated by corresponding gauge or guide marks, as shown. If the two templates were applied to the frame angles simultaneously, they would be properly placed when their guide marks were opposite each other, but as they are applied separately, a mark is made on the heel of the bar, as already described. The end of the bar might be taken as a guide in adjusting the templates, but, as a rule, the ends are rough and irregular.

The frame angles towards the vessel's ends, which vary in shape, are marked, punched, bent, and bevelled by reference to the scrive board, as already described for ordinary frames. If the vessel has a flat-plate keel, and it is fitted before the frames are erected, the shell flange of the latter should be left blank in way of it, for it is better to drill these particular holes in the ship. After the frame angles (those at the ends which vary in shape) are punched, bent, and bevelled, the curvature of each one is adjusted on the scrive board, the shell landings nicked in and the ends marked for cutting. While each one is lying in position on the scrive board, a short template, G (Fig. 4, Plate 84), which is also used for marking

the holes in the end of the floor (Fig. 8), is placed, as in Fig. 7, in line with the margin plate scrive, and with its guide mark coincident with the level line LL on the scrive board; when so placed its lower end overlaps the frame angle, and the guide hole is marked through upon it. This hole (blackened in the sketch) serves later for chalking in the frame curve on the floor plate.

The **reverse bars** on the upper edges of the floors are all perfectly straight, and they are cut and punched by the templates H and J, Fig. 4, Plate 84. That shown at J is for the floor flange; it is identical with the upper batten of the floor template, and the outer ends of those bars beyond 'midships which vary in length are marked upon it. That shown at H is for the tank-top flange, the landings of the tank-top plating being marked upon it. Separate templates are provided for those reverse bars in the machinery space, or elsewhere, in which the rivet holes are of odd size or spacing, or which may be specially arranged to take the engine seating, boiler stools, bulkheads, etc.

The 'midship **floor plates** are marked entirely from the skeleton template shown in Fig. 4, the upper and lower edges of which are identical with the frame and reverse-bar template J and C. After marking the holes and edges from the template, the position of the air, limber, and manholes, are marked (the latter by an oval template), all in number and position as indicated on the 'midship section or frame list. The level line LL is struck in, and marked permanently by centre-punch dabs. The edges are sheared within the line, so as to leave a clearance from the shell and other plating. All marks are made on the same side of the plate; this is the faying surface for practically all the rivet holes, the edges, therefore, should be sheared from the other side, but if the shear knife is in good order this is unimportant. The manholes are punched in the hydraulic machine described in Art. 540. Sometimes, to avoid the work of shearing the 'midship floors, an outline mould is sent to the steel works, so that they may be cut there exactly to the finished shape.

The floors towards the ends, which vary in outline, are marked as follows, and as shown in Fig. 8, Plate 84. The full-size, 'midship template is first applied, with its upper edge and inner end flush with those of the rough plate, and the holes in these parts, and in the cross-bar for the intercostal plate, marked through. The level line LL is struck in, also the line of the outer end of this particular floor (as marked on the floor template), and a short piece of the lower edge near the keel. The template is then removed, and the holes in the outer end of the floor (as just struck upon it) marked by the short template G; this being applied as shown, with its level-line mark coincident with the level line LL. The frame angle, already bent, is then applied, as shown, with its keel end coincident with the chalk mark made at that place, and with the guide hole, specially marked at its outer extremity, coincident with the guide hole in template G, this being again applied in position, as shown in Fig. 8. When thus placed, the frame angle occupies its proper position, and completes the outline of the floor, precisely as scrived on the boards.

The parts of a cellular double bottom are differently arranged at different parts; under the engines, for instance, additional intercostals are introduced, and towards the ends the ordinary line of intercostals may step inwards towards the centre line, and the frame angles may be doubled. These variations are indicated to the workmen on the plans and frame list. In the case of the intercostal plates, the extra ones may be embodied in the 'midship floor template, the workmen, of course, only using those which are required for the particular floor under treatment.

The inner and outer ends of the floor template, and the cross batten for the intercostal plates, are identical with the small template used for marking the floor flanges of the connecting angles. The length of the margin and intercostal plate connecting angles may diminish towards the vessel's ends, in which case the different lengths are marked on the templates; and if the variation is considerable, different templates, having suitably spaced holes, may be used for different batches of angles. The margin connecting angles should be cut short at their lower ends, to avoid a three-ply rivet through the frame and another through the margin-plate shell angle. They are the only vertical angles which are bevelled.

When the floor plates, with their various angles, are prepared in the foregoing manner, each one may be riveted up complete (by hydraulic machine) before erection. In the case of the angles for the connection to the vertical keel, particular care must be taken that they are perfectly square with the level line, for, if not, the floor, when riveted to the keel, would not stand out from it at the proper angle. Very commonly they are riveted to the vertical keel instead of to the floor plates, but if there are two of them there may be difficulty in inserting the floor plates between, and unless the keel is hydraulic riveted this method entails extra hand riveting. The vertical angles for the **intercostal plates** may be machine riveted either to the floors or intercostal plates. The latter method is advantageous in that all the parts may be marked and punched in bulk, by pattern template, and machine riveted before erection. The former, however, is the more generally adopted; it is advantageous in that as each plate is taken account of by a transferring template, discrepancies in fit are less likely to occur, and the final hand riveting work is easier, for the hammer blows, being athwartships, are not so hampered.

Watertight floors differ from others in that they are not pierced with holes, and have a continuous marginal frame angle (see Fig. 2, Plate 18). The best way to make them is to provide a pattern template for each one, from the mould loft, from which the plate and its angle frame may be prepared independently, without reference to the scrive board. The angle frame is conveniently made in several pieces; the joints of which, if well fitted, do not require bosom pieces. The corners are turned and welded by angle-smiths. The different lengths of the bar are first cut approximately to length by the plater, who marks upon them the positions of the corners, bends and bevels those parts which require bending and bevelling, and punches the rivet holes in the shell, tank-top, and margin-plate flange, all at watertight pitch. They are then handed to the smith, who knees the corners in accordance with the template. The different parts are then fitted together by the plater, so that they may form a continuous close-jointed frame, having the precise outline of the template, the holes in which are then marked on its floor flange. At this stage, all holes are either marked or punched, excepting those in the flange which connects to the vertical keel. These are now marked by a short pattern template (having holes bored at watertight pitch), the same one being used to mark the corresponding holes in the vertical keel, and, of course, to secure the necessary correspondence of the holes, it is applied in each case from the two-foot level line as a base. It may not be possible to punch a few of the rivet holes in way of the welded corners; these, therefore, are drilled. Having marked, cut, and punched the plate from the template, it and the angle frame may be riveted together forthwith. If the vessel has a bar keel, the space above the knuckle of the garboard strake is filled in watertight with a piece of iron, forged to the required shape.

Art. 494. The **side frames** above the tank margin plate, with their

reverse bars and margin brackets, are prepared in the manner described for ordinary frames. The frame angle and reverse bar, being bent and adjusted, the margin bracket plate, as yet untouched, is laid on the scrive board, with its upper edge coincident with its scrive, and with its inner end just overlapping the margin-plate scrive, as shown in Fig. 5, Plate 84. The latter represents the inner surface of the margin plate, and the line of its outer surface is struck on the bracket with a chalk line. The frame angle is now laid in place, with its bilge portion overlapping the bracket; as the latter covers the frame scrive, one or two gauge marks are made, previously, on the boards, say 12 inches out from it, which permit of the frame being placed exactly over it. A pattern template K is now applied to the upper edge of the bracket; the same one is used to mark the reverse bar, care being taken, of course, to place it in the same position with regard to the frame, in each case (as described in Art. 488).

The side frames are connected to the tank margin plate by short angles (M, Fig. 3, Plate 84), one in small vessels and two in large. One of them is riveted to the margin plate before the side frames are erected (sometimes by hydraulic machine before the margin plates are erected), for it is then more accessible for riveting. To save labour and expedite the building work, it is very desirable that immediately the side frames are erected they should be bolted in their proper positions to the connecting angles on the margin plate. This, of course, involves the punching of the holes in both parts, the bracket plate and connecting angle. They always are punched, of course, in one of the parts, but sometimes they are drilled in the other, pending which operation the frames are held temporarily in place by clamp plates, shores, and ribbands (Fig. 2, Plate 96).

When punched in both the angle and bracket, the required correspondence in the holes may be secured by marking both parts with a pattern template. In applying this to the two parts, it is essential that it should occupy the same position with regard to the heels or outer surface of the frames, otherwise the side frames, when erected, would not form a fair surface with those within the tank. This may be best accomplished by assuming a base line on the margin plate, parallel to, and, say, 12 inches within the outer surface of the frames, with which a corresponding mark on the template may be adjusted when marking both parts. As shown in Fig. 5, Plate 84, M is the template, and the guide mark shown upon it represents the 12-inch base line on the margin plate, as set up from the frame scrive. To mark the holes in the bracket plate, the template is applied to it, as shown in Fig. 5, with its edge coincident with the outer surface of the margin plate, and with its guide mark coincident with the 12-inch base line. The bracket flange of the angle is marked by the same template, and a nick is made in its heel opposite the guide mark. Its other flange is marked by applying the angle itself to the margin plate, as shown in Fig. 6. The latter, with all its holes punched, is already screwed up in its place in the ship, and the 12-inch base line is sheered in on its outer surface, parallel to the heel of its fore-and-aft shell angle, which represents the outer surface of the frames (Art. 516), and, when applying the connecting angle to it, it is adjusted with its nick coincident with the 12-inch base line. When marked thus, the connecting angles may be punched and riveted, forthwith, to the margin plate, and any holes punched in their transverse flanges will—if the work has been carefully done—correspond with those also punched in the bracket plates of the side frames, so that, when the latter are erected and bolted in place, they will form a fair continuation of the frames within the tank. When there are

two connecting angles, the second one is marked in place after the side frames are erected.

Art. 495. Web frames should be made concurrently with the others, so that they may be riveted up and erected with them. The workmen are provided with a plan showing the structural details of each one. After the shell and face angles are punched, bent, and bevelled, the margin bracket and various plates, all specially ordered, are laid in position on the scrive board, with their ends overlapping. Web frames which are narrow and have an easy curve may be made of a single parallel plate, heated and bent to shape on the slabs. Otherwise they are ordered with a sufficient margin of breadth to permit of their being cut to shape, in which case, to save scrap, they may be made of two or three plates jointed together.

Before laying the plates on the scrive board, the positions of their joints and of the various decks and side stringers are struck in with chalk, and these lines are afterwards transferred to the plates. Afterwards, the shell angle is laid in place over its scrive, the position of which, though hidden by the plates, is determined by gauge marks made previously on the boards. One of the face angles is laid in place at the proper parallel distance from the shell angle. The outline of the web is now chalked in from these two bars, the ends of which are marked for cutting, and their holes marked through on the plates. If there is only a single face angle, and it is turned the reverse way to the shell angle, it is usually templated from the web plate after the latter is erected in the ship; the line of the inner edge of the web plate, in such a case, being lifted like that of the outer, by gauge marks. Holes are also marked on the fore-and-aft flange of the face angle, to take the diamond straps in way of the side stringers. Where there are two face angles, one of them is marked from the other as a pattern. The rivet holes for the lap joints of the different plates may be marked by a pattern template, as shown in Fig. 17, Plate 81; or, after marking the overlapping one, its end may be lifted an inch or so to permit the use of the marker shown in Fig. 6, Plate 91; or the holes may be punched in it, as a preliminary operation, before laying it in place. The holes in the lower end for the connection to the tank margin plate are marked as described in Art. 494. Those for the connecting lugs of the side stringers are also marked; a blank space has been—or should have been—left at this place in the frame and face angles, and holes are now suitably marked in these to take the ends of the stringer lugs (Figs. 5 and 7, Plate 7). If the side stringers pierce the web, suitable apertures are marked for cutting (Fig. 8). If a beam connects to the web frame by a knee plate (Fig. 2), the latter may be fitted and riveted, in the first place, either to the beam or to the web; and, while all the remaining rivet holes may be punched in one of the parts, only two may be punched in the other, by a pattern template, as described in Art. 497.

When all the holes, etc., are marked, the plates and angles may be cut and punched, and all parts screwed together ready for riveting, which, as with other frames, is usually done by hydraulic machine. In the case of web frames which are pierced by side stringers, it is usually better to defer the riveting until the vessel is framed and the side stringers fitted, for if riveted before this it may be difficult to reeve the long stringer bars through the holes in the webs. Web frames which form a continuation of a shallow floor (Fig. 2, Plate 7) cannot well be riveted together as one piece before erection, for their contour might alter during the riveting, and, being inflexible, they cannot yield to the fairing ribbands like ordinary frames. And, moreover, in a large vessel, a web frame extending from gunwale to gunwale would be too heavy and cumbrous to erect with the ordinary lifting appliances.

CHAPTER XXXV.

Art. 496. The transverse **bulkheads** may be built in the ship, piece by piece, or they may be prepared on the scrive board. The latter is the usual plan, for the work is then easier, and as it may be done at an early period, immediately the bulkhead frame angles are bent to shape, the bulkheads may be erected at the same time as the frames. When constructed in this way, it is important that their outline should be precisely that shown on the scrive board, for, if not, they would not, when erected, conform with the adjacent frames and beams. And, further, as they form unyielding diaphragms, while the adjacent frames are more or less flexible, it is important that they should be fitted in place before the frames are finally faired, so that they may be taken as a sort of basis in the fairing work; and as no building operations can proceed in the ship until the frames are faired, the bulkheads should evidently be taken in hand at an early period, so that they may be ready for erection immediately after the frames. If, owing to the non-delivery of material, they cannot be made until the frames are erected and faired, it is better to build them in the ship, but it may still be advantageous to fit the marginal parts on the scrive board, the frame angles being laid aside for the purpose.

The **bulkheads may be conveniently made on the scrive board**, because their correct outlines are given here, together with the position of the decks, tank top, side stringers, etc. In order not to interfere with the frame-making operations on the scrive board, their outlines are usually scrived on some other board or floor. The following is a common mode of procedure in making a bulkhead such as that shown in Fig. 5, Plate 33, in which the plates are disposed vertically, and the alternate stiffeners placed on the seams. A sketch of each bulkhead is, of course, supplied to the workmen, showing every structural detail, and giving figured dimensions for the sizes and positions of the various parts. The first operation is to strike in with chalk-line, on the boards, the various plate edges, stiffeners, doorways, tank top, tunnel, side stringers, etc., all in position as shown on the plan; the beam line of the decks, if not scrived in, being obtained from the beam mould (Art. 497). Gauge marks are also made at intervals, say, 12 inches out from the frame scrive, so that when this is covered by the plates its position may still be determined (Fig. 5).

In making bulkheads and the like, where large numbers of rivet holes must be marked and punched in the plate edges and stiffening bars, all in straight rows and at a certain pitch, it is advantageous to prepare, in the mould loft, a pattern template, in the form of a long batten having a row of holes at the required pitch (A, Fig. 5, Plate 33). The holes should be bored precisely the same distance apart and in perfect line, for then, one part of the batten being the same as another, any part of it may be used to mark corresponding holes in conjoined parts, and, if shorter than the parts to be marked, it may be applied consecutively. There should be

two such templates, one (A) for the watertight riveting of the seams and one (B) for the widely pitched rivets in the stiffeners. In the absence of these pattern templates, the plater usually prepares others for himself, by punching a row of holes half on and half off the edge of a long, flat-iron bar, say, $1\frac{1}{2}$ inch wide by $\frac{1}{4}$ inch thick (Fig. 9). This is practically one of the batten templates just described, split up the middle, but, of course, as the holes are not precisely equidistant nor in perfect line, it must, when marking two conjoined parts independently, be so adjusted that the same part of it is applied in the same position on both. The fact that its edge represents the centre of the row of holes is advantageous, because any holes already punched in one of the parts (in odd positions between those in the template) may be seen when the template is in place, and easily marked upon it for transference to the other part. Thus, in Fig. 9, the odd hole, D (occurring in the plate), may be noted on the template as shown, and be readily transferred to the stiffener.

After chalking the various structural features of the bulkhead on the boards, the alternate plates (E, G, etc., Fig. 5, Plate 33) are laid in position, and any lines which they cover are struck upon them. After this the intermediate plates (F, H, etc.) are laid in place, with their edges overlapping the others; but first, and before conveying them to the board, their edge rivet holes must be punched, so that they may be marked through on the plates below. The holes are marked by one of the pattern templates just described; but as one hole must fall on each horizontal stiffener, and one in the tank-top connecting angle, the template is first laid in place on the board as shown in Fig. 5, and if, upon adjustment, its holes do not fall in with these parts (in many cases the position of the horizontal stiffeners, when lined off on the boards, may be adjusted to suit the spacing of the holes in the batten template), suitable holes (shown in black) are marked upon it in the required position. The template is then applied to the edge of the plate, and the holes, ordinary and special, marked upon it, leaving, however, a blank space in way of the deck angle, the position of which and of the tank top has been noted upon it; the ends of the plates are not marked at this time. Both edges of all the overlapping plates are marked in this way, and most of them may usually be marked straight off, with the same template. To avoid the necessity of shearing the edges, the full width of the plate is usually maintained, if, as seen from the plan, this does not interfere with any feature of the design. Of course, if the edges are rough or irregular they must be sheared, and, for caulking purposes, they should be sheared *to* the faying surface (Art. 323). Having punched the plates, they are laid in place on the scrive board, with their faying surface—as determined by the punched holes—downwards. The holes are then marked through on the plates below, and any chalk lines covered by them struck in anew.

Concurrently with the marking of the edges of each plate, the vertical stiffening bars which fall upon them are marked in precisely the same way. Their ends are also marked for cutting, about 1 inch clear of the tank-top and deck angles, and holes are marked in the lower end of their standing flange for the bracket connection to the tank top. When punched and cut these bars are finished and done with, and they may be put aside to await the erection of the bulkhead in the ship.

The horizontal stiffeners, and those vertical ones which fall between the plate edges, are marked by pattern template, B (Fig. 5, Plate 33), having widely spaced holes, which serves also for marking the corresponding holes on the bulkhead plates. The stiffeners, when punched, might themselves be laid in place to mark their holes through on the plates, but this would

involve extra labour in handling and transporting, and if the bars did not lie flat on the plating, it would be awkward to transfer their holes. The horizontal and intermediate vertical stiffeners cross one another at various points, and the holes in both parts are arranged clear of the crossings. In the case of the horizontal stiffeners, account must be taken of the holes already punched in the vertical seams, by trying the template in place (as shown in Fig. 5) and marking upon it the position of any edge holes with which its own do not coincide. When a full-breadth batten template is employed, hidden holes may be marked upon it with a reverser. Or a short batten, having three holes in it, may be used, as shown in Figs. 6, 7, and 8; this is applied as a sort of gauge (before the hole is covered, as shown in Fig. 6), with one of its end holes over the edge hole in question, so that marks made through the other two (anywhere on the plate) may permit of its being replaced as before (Fig. 8) to locate the third when covered. Sometimes the rivets in the seams are arranged to clear the horizontal stiffeners, which, by avoiding an awkward three or four-ply rivet, saves some trouble. But a wide rivet pitch then occurs at these places, which, although unimportant in ordinary bulkheads, might not be compatible with the perfect watertightness necessary in those of the peaks or deep tanks. Sometimes these particular holes are drilled in the horizontal stiffeners, or the rivets may be closed with countersunk points before fitting them.

The deck line may be marked on the plates by laying the beam mould in place. The rivet holes in the deck angles and in the plates may be marked independently by a pattern template (sprung to the curve of the deck), but it is better first to punch and bend one of the angles, and then lay it in place to transfer its holes to the plates (Fig. 5, Plate 33). And in marking it, holes should be suitably placed to take the seams of the plating (or to clear them), in which a blank space has been left purposely. It should run over the frame angle, and in the case of lower decks, a kneed corner piece should be fitted at this place, as shown in Figs. 5 and 7, Plate 22. If there are two deck angles, one is marked from the other as a pattern, but, of course, only one need extend over the frame. The lower ends of the plates are struck in rather more than twice the thickness of the tank-top plating above the scrive, which, of course, represents the heel of the reverse bar within the tank. The holes for the connecting angles (or angle) to the tank top are marked now on the plates, but the angles are marked after the bulkhead is erected in the ship, because until then the position of the holes in the tank top, and of those in the bulkhead relatively to the tank top, is uncertain.

To mark the frame line of the bulkhead, one of its double frame angles (port and starboard) is laid upon it, precisely over its hidden scrive, as determined by the gauge marks previously made on the boards (Fig. 5, Plate 33); its heel is then drawn in, and its holes marked through on the plating. If the forward side of the bulkhead is uppermost, then, of course, the forward frame must be applied; and in the case of a bulkhead which has only a single frame angle, care must be taken to lay it out on the boards with the surface on which the frame is fitted uppermost, otherwise the latter could not be applied to transfer the holes. Before removing the plates for punching and shearing, any odd lines of rivets for casing angles, stringer lugs, etc., are marked upon it, and any scores or notches required to pass the side, or deck stringers, are marked on the marginal part, with suitable rivet holes for the watertight collar angles, all as indicated on the plan. The plates are, of course, shorn about $\frac{1}{4}$ inch clear of the heels of the frame, tank-top, and deck angles.

Art. 497. The **beams** should be made at the same time as the frames, so that both may be erected together. A separate bar is ordered of the proper length for each one. As delivered from the steel works, they are usually far from straight; if not twisted, corkscrew fashion, they may be faired in the beam bender; if twisted, they must be heated and faired on the slabs, and as this causes much additional labour, they should be ordered free from twist. Formerly, when beam-bending machines were worked by hand, it was common to heat the bars and bend them to the required camber on the slabs; and sometimes, to avoid this work, a beam mould was sent to the steel or iron works, so that the bars might be bent to shape while still hot after rolling. At the present time many shipyards find it advantageous to supply templates, moulds, and battens to the steel works, so that the beams may be finished there, complete in every respect, ready for erecting in the ship.

In **making solid beams** there are three distinct operations—marking the holes, etc., punching and bending the bars, and making the knees. Two platers usually undertake the work, one of whom does the marking and the other the punching and bending. For their guidance they are provided with a **beam list**, a plan of the deck, a beam mould, battens, and bevel boards. The beam list describes each beam. It states the scantlings and whether the beams are to be punched for deck planks or for plating, or what portion for the former and what for the latter (as determined by measurement from the centre line), with the pitch and size of the rivets and deck bolts. It also states which beams are reversed or cut to form hatchways, etc., and the distance of their inner ends from the centre line, and a sketch is provided showing the nature of the connection to the coaming plate, so that suitable rivet holes may be punched for the connecting lugs and coaming angle; those beams from which it may be required to remove at places half of the flange or bulb, and those in the web of which rivet holes are required to take hatch coamings, bulkheads, or casings; the distance of each pillar from the centre line, so that the necessary holes may be punched in the web for the connection of their heads or of the lugs for a pillar-head stringer. Sketches are also provided of the beam knees, showing their shape and size, and the number and disposition of the rivets.

The exact length of each beam is provided from the mould loft on a batten, the full length of which represents the half length of the 'midship beam (Fig. 22, Plate 81). When **marking a beam** for cutting, the batten is held with the breadth mark for that particular beam flush with one of its ends, the inner end of the batten is then over the centre of the beam, and its position being nicked in, the batten is reversed and the other end marked, there being usually an inch or so of spare length. The web of the beam may require to be cut at an angle, to suit the line of the frame or beam knee; these angles are supplied from the mould loft, on a bevel board (Fig. 23), and they are indicated on the beam by making a couple of nicks, on the web (Fig. 22). With tee-bulb beams, part of one flange must be cut away to clear the reverse bar or transverse flange of the frame angle (Figs. 7, 8, and 9). The precise configuration may be indicated on a template provided from the loft, as shown in Fig. 10. The 'midship beam ends may be marked directly from this template; one flange of those towards the bow and stern should be cut at an angle to clear the bevelled reverse bars (Fig. 9); very commonly, however, this work is roughly done, the flange which would foul the reverse bar being simply cut well back. The length of this template represents the breadth of the stringer plate amidships; all the rivet holes are bored in it, and they are suitably placed to take the gunwale and waterway bars, whose positions are indicated. All of the

'midships beams are marked by it, the waterway bar and inner edge of the stringer being nicked in on each one. The stringer tapers in breadth beyond the half length amidships, and its breadth at each beam is pencilled across the template as shown. The holes in these end beams may be spaced by measurement, to suit the particular breadth of the stringer, but those in way of the gunwale and waterway bar must be accurately marked to take these parts; and a blank space should be left at the landing edge, for where the stringer tapers its position is uncertain. With deep frames it is sometimes necessary to cut the beams clear of the gunwale bar (see Fig. 8, Plate 81), so as to avoid a bad three-ply rivet, half on and half off the beam end (Fig. 3, Plate 12). A similar template is provided for the beams of the lower deck, and in this, holes are specially arranged in way of the continuous gunwale bar within the reverse frames (Fig. 15, Plate 89).

The remaining holes in the beam are punched to suit the deck material. If the deck is plated account must be taken of the position of the landing edges, as shown on the plan; or, for this purpose, a batten having these marked upon it may be supplied from the loft. As the landings are usually parallel to the vessel's centre line, one batten may suffice; if their distance from the centre line varies at different places, special battens may be supplied for the beams of these places, or different arrangements of landings may be marked on the same batten, with proper indications showing to which beams they apply. The batten being applied to a beam, holes are carefully marked in the centres of the landings, and the others spaced in between, at a pitch not exceeding that given on the beam list (5 or 7 diameters, Art. 296). Sometimes a blank space is left in way of each landing, so that holes may be accurately beared in the ship after the plate edges are lined off. Instead of a batten, it is advantageous to provide a long template batten having all the rivet holes bored in it, for the work is then more likely to be uniform and accurate.

When the deck is of wood (as in Fig. 18, Plate 56), rivet holes are punched only in way of the stringers, tie plates, and other local plating; elsewhere bolt holes are provided, being spaced to suit the breadth of the planks. The position of the tie plates, etc., is first chalked on the beams, in accordance with the measurements given in the beam list or as shown on the plan of the deck, and suitable rivet holes marked at these places. The position of the centre of each deck plank, from the centre line, is provided on a batten from the loft, and a bolt hole is marked at each spot; if the beam has a double top flange, they are zigzagged (Fig. 18). The batten should (if practicable) be prepared from measurements taken from the actual planks; for if, when these are planed and finished, they should be slightly broader or narrower than their nominal size, the holes, in the case of a large number of planks, might fall considerably off their centres; but even then they may not fall in the centres of the planks, if, as is usual, the beams are bent after punching. In many cases therefore, to ensure the bolts being in the centres of the planks, the holes are beared in the beams, after the planks are lined off.

Holes are marked in the web of the beam for the connection of the pillar heads, the position of which is given on the beam list. For this purpose a small pattern, sheet-iron template, bent to the shape of the pillar head, may be employed, a similar one being used by the smith for drilling the holes in the pillars. The holes required in the top flange to take the heels of the pillars are drilled after the pillars are erected. If there is a pillar-head stringer (Fig. 17, Plate 12), the holes in the beams, for the connecting lugs, are marked by a small template, from which the lugs also

may be prepared. When the beams have plate knees, the rivet holes in the web may be marked from a pattern template, which also serves for marking the knee plates (Figs. 1 and 2, Plate 81). The holes next the end of the beam, which take rivets through the frame angle (A, Fig. 6), are not marked at this time if the corresponding holes are already punched in the frame.

When the marking is completed as above, the **beams may be punched and cut to length.** Tee-bulb beams have usually welded knees, and in the absence of the special shearing machines described in Art. 533, they may be cut to length by the smith who makes the knees, and who also cuts back one flange to clear the reverse bar. If the beam knee is to be a plate, the bulb on one side of the web must be removed (Fig. 12, Plate 81); if cut off by hand, a number of grooves are first made across the bulb, about two inches apart, whereupon the parts between may be split off with a chisel and sledge-hammer (Fig. 13); some beam-bending machines are arranged to do this work (Art. 533). The cutting away of the bulb is now often dispensed with, however, by merely bending it to one side in way of the knee plate, as shown at A, Fig. 12. After the beams are punched and cut, they are faired and bent to the camber of the deck. They are punched before bending, for the double reason that a straight bar is more easily manipulated at the punching machine, and because the punching operation may cause an alteration in curvature. Beam-bending machines are described in Art. 535, and one is illustrated in the diagram, Fig. 2, Plate 95. Before bending the beams to the required camber, they are faired sideways, and any unfairness in the bulb corrected. If the bulb has any sharp bends or kinks, it may not be possible to fair it in the machine, for the three points at which the bending pressure occurs may be too far apart; in such a case it may be faired by the rail-straightener shown in Fig. 2, Plate 83; but if the bulb is light and sharply bent, it may be necessary to heat it, for if it be attempted to fair it cold, the buckle may simply jump from one side to the other; in ordinary cargo vessels, however, no great care is taken to fair the beams laterally.

To bend the beams a beam mould is provided from the loft, in the form of a slab of wood, one edge of which is cut to the camber of the deck (Fig. 21, Plate 81). When the beam is in process of bending, its curvature must be constantly checked by applying the mould, but as to do this with a full-length mould would, owing to its unwieldiness and lack of rigidity, be inconvenient and unsatisfactory, a short one, half or one-third the length, is usually employed. The procedure is then as follows. First the beam is bent approximately to the required camber, then the short mould is applied to one half of it, and any discrepancy in the curvature of this portion made good; the curvature of the other half is then corrected in the same way, after which the mould is applied to the central part, and when this also is adjusted to correspond, the whole beam must necessarily have the proper camber. If the curvature of the finished beam is fair and regular, it is not essential that its camber should be precisely that required in the ship, for any small discrepancy is readily corrected by the shores and pillars. Sometimes they are bent with a little excess of camber, to allow for the natural sag which occurs before the pillars are fitted.

After the bending process, the **beam knees** are taken in hand; if of welded type, the work is done by the smiths (Arts. 133 and 498). **Plate knees** are usually ordered from the steel works, each one separately, in accordance with a dimension sketch. Otherwise, they are ordered in long strips, of a suitable breadth to cut up with as little waste as possible. The shape of those beyond the flat 'midship body varies with the angle which the

ship's side makes with the beam; these angles are supplied to the men on a bevel board (Fig. 23, Plate 81), which, with a dimension sketch of the knee (giving its length on frame and beam), enables them to cut the different plates to their proper shape (see Fig. 1). The rivet holes for the beam connection are marked by the same template that is used for marking the corresponding holes in the beams (Figs. 1 and 2). When the knee plates are cut and punched, they may be riveted forthwith to the beams (Fig. 3).

The next operation is to mark one or two holes in the knees, by which the beams, when erected, may be bolted temporarily to the frames. They are marked by the template shown in Fig. 4, Plate 81, a duplicate of which (Fig. 5) is employed to mark the corresponding holes in the frames. In the case of the frames, all the holes are punched, and the same holes might also all be punched in the beam knees, but as the sources of error tending to produce bad holes are numerous, and practically unavoidable, not more than two are punched at this time, the remainder being drilled in the ship—sometimes, indeed, none at all are punched, all being drilled in the ship. The holes in the frame angle are marked as it lies in position on the scrive board, as shown in Figs. 5 and 16, and it is evident that if the beam were also laid on the scrive board in its proper position relatively to the frame, the holes in its knee would be accurately marked if the template were applied to it in exactly the position it occupied when marking the frame. In practice, however, this procedure cannot well be carried out, for, among other reasons, the beams and frames are made by different sets of men at different times. A good method, which is often adopted, is to provide a special **beam scrive board**, as shown in Fig. 20, on which there is scrived the full-length 'midship beam, and, on each side, a short portion of every frame to which a beam connects, all in their proper positions with regard to the centre line, but all with their beam lines coincident with the one beam scrive. To mark the beam knees, each beam is laid in position on the board, with its upper edge coincident with the scrive and its centre-line mark exactly over the centre line (Fig. 20). The template is then applied to each knee, as shown in Figs. 4 and 20, with its outer edge exactly over the frame scrive, and its rounded end flush with the top of the beam, and when so placed one or two holes are marked through.

It will be observed that the templates in Figs. 4 and 5, Plate 81, are not identical in the matter of breadth, for while the former is applied with its outer edge coincident with the frame scrive, the latter must be kept about $\frac{1}{2}$ inch within it, in order to clear the shell flange of the frame angle. In the case of plate knees, they may or may not be riveted to the beam at this stage; in the latter case they are laid in position upon it, and, while marking upon them the two frame holes, the holes already punched for the connection to the beam are marked through on the beam. By this method the coincidence of the two frame rivet holes is less assured, because the plate, when riveted to the beam, may not occupy precisely the position it did when it was laid upon it to mark the holes. In such cases, however, this disadvantage may be avoided by not riveting the knee plate either to the frame or beam until the beams are erected in the ship. The half-beams at the sides of the hatchways, etc., are adjusted on the board with their inner ends at the proper distance from the centre line (the line of the hatch coaming plate being chalked on the board), and when so placed the holes for the lugs may be marked on their ends by template, and the lugs, being prepared from the same template, may be riveted to the beams at the same time as the knee plates.

Very commonly, instead of the beam board just described, a broad **beam mould** is provided (Fig. 21, Plate 81), having the frames scrived across it in the same way; and if there are two decks, and both have the same camber, both sides of the mould may be used. But although this mould gives the same information as the scrive board just described, it is less convenient to use.

Built beams, consisting of a bulb bar and two angles, are made as follows: The two angles are first bent to the camber of the deck, or slightly in excess of it to allow for the straightening effect of the punching. The holes in the vertical flanges may be conveniently marked in both bars by a pattern template, after which the two bars are laid alongside of each other, and their ends and the holes in the deck flanges marked, as already described. In these beams the ends of both of the top bars are sometimes cut clear of the frame (Fig. 11, Plate 81) so as to avoid a four-ply rivet through the frame, and an awkwardly situated three-ply rivet through the gunwale bar. Sometimes, instead of marking both angles independently by a pattern template, one of them is punched and applied to the other as a pattern, but this involves extra handling. The bulb plate is now taken in hand; it is first faired and bent to the camber, if twisted and irregular, it may be necessary to heat it and fair it on the slabs, or it may be passed through the rolls. One of the angles, now punched and cut, is then applied to it to mark the holes. The angles may not have the precise curvature of the finished beam, but if they are of ordinary light scantlings, the stiff bulb plate is well able to pull them into place. In this type of beam the knees are often welded, which work is taken in hand before the angle bars are fitted. The angle bars are practically always hydraulic riveted to the bulb plate, this work being particularly suitable for machine riveting.

Art. 498. The method of forming different kinds of **welded knees** is described in Art. 133, and illustrated in Plate 12. Suitably shaped anvils are, of course, used for the work. In the case of **slabbed knees**, such as that shown in Fig. 6, in which the bulb is carried down, each knee piece, or slab, is cut to shape by the smith from a long bulb bar. A represents the bar after the first heat, during which the bulb is cut off and its end thinned down as for a scarph. The bulb is cut off by a chisel, which is held at an angle so as to leave a bevelled edge. The knee piece B is now prepared for welding, by heating it and staving up the welding edge and the end of the bulb, all on the bevel, so as roughly to match the corresponding edge of the beam. The knee piece and beam are then heated in separate fires to a white heat, and welded together forthwith. A perfect union of the two parts at the ends of the weld, *i.e.* at the bulb and at the outer edge of the knee, is not always secured in the first heat, these places are, therefore, finished off with one or two additional heats, and if, as is usual, there should be a local lack of substance, a piece of iron is heated white hot and hammered in; iron is preferred to steel for this purpose, for the reasons noticed in Art. 319. Beam knees are sometimes carelessly welded, the line of weld being often clearly visible on one side (the underneath side during the weld), and in exceptional cases the metal may be rendered so brittle by overheating that the knee may be broken off, across the weld, by a blow from a sledge-hammer.

Only small beam knees can be satisfactorily welded in one heat; if the length of the welding edge exceeds, say, 9 inches, some parts are very likely to cool below the welding temperature before they are properly hammered together. In such cases, therefore, one of the edges is cut back locally, as shown at D, Fig. 7, Plate 12, so as to leave in contact only as long a

portion as can be welded in the first heat. The condition of the knee after the first welding heat is shown at E, Fig. 7, and the weld is completed during the second by welding a suitably shaped piece of steel or iron into the gap. The reason for cutting back those parts of the edges which cannot be welded in the first heat, is that, as the furnace blast, during the second heat, may then pass between and impinge upon them, they are the first parts to attain the required welding temperature. The proper heating of the two parts is the principal feature of good welding work. When heated in a smith's fire, a piece of steel or iron does not become uniformly hot, the parts directly exposed to the blast may become white hot and begin to burn while the remainder may be comparatively cool. Now, in heating for a weld, the only part that should become white hot is the welding surface, for if, through careless manipulation of the fire, some other part became white hot, it might be overheated, burned, and damaged before the welding surface attained the desired temperature. The making of turned beam knees is described in Art. 133, and illustrated in Figs. 11 and 12. When made at the steel works they are heated by gas jets, these play upon the seam, which, when brought to the required temperature, is struck rapidly, on both sides simultaneously, by machine-driven hammers; to give the necessary surplus material for the thinning effect of the hammer blows, strips of small, specially made H-section iron are placed in the seam, which also serve to hold the knee plate in position until it is welded.

After welding the knee, the smith cuts its outer edge to the proper bevel, for which purpose he is provided with a bevel board and breadth batten, the latter giving the half length of each beam from the centre to the outer edge of the knee. In beams which have a double top flange, he must also cut back one flange to clear the reverse frame, and it is usually he who cuts the beam bar to length, by hot chisel and hammer, *i.e.* those beams which have welded knees, and whose section is such that they cannot be cut with the available shearing machines.

Art. 499. Bar keels are described in Arts. 59 and 75, and illustrated in Fig. 11, Plate 5, and Fig. 6, Plate 85. The various lengths are usually delivered "*finished*," *i.e.* with the holes drilled and scarphs machined, in accordance with a detailed dimension sketch supplied from the shipyard. If forged in the yard, or delivered "*rough*" from outside, the scarphs are first blocked out in the smith's shop, and are then machined so as to fit accurately with one another and occupy their proper fore-and-aft position. Unless specially ordered, rolled bars are not straight when delivered; if of light scantlings and free from twist they may be faired in the beam bender, but if heavy or twisted they must be heated and faired on the slabs.

The **holes** may be conveniently **marked by a pattern template**, supplied from the loft, on which also the positions of the frames are marked for nicking on the keel bars, all as described in the next Article on side-bar keels. The holes are arranged in a fixed relation with the frames, so that they may suit the butts of the garboard plates which fall midway between the latter; and the scarphs of the various bars should be so disposed as to fall in with the ordinary arrangement of holes, and be clear of the garboard butts. Owing to their rounded knuckle, the garboard plates leave the keel at a distance from its upper edge of three to four times their thickness (Fig. 6, Plate 85), and, accordingly, the centres of the upper row of rivet holes should be placed at this distance, plus one diameter below the upper edge; forward and aft, however, where the garboard plates have less knuckle, they may be higher up. The centres

of the lower holes are placed about two diameters clear of the lower edge of the keel; in coasting steamers it is well that this distance should be increased at the after end, to allow for the wasting action noticed in Art. 75.

Keel bars may be drilled with any **drilling machine.** With ordinary vertical machines they require to be shifted and adjusted for every hole; radial-arm machines are the best, because they can drill a large number of holes without any adjustment of the keel bars, and two or more may operate simultaneously. In some yards, to expedite the work, a vertical machine capable of drilling two holes at the same time is advantageously employed. Multiple drilling machines, capable of drilling from 20 to 40 holes simultaneously, have been tried in some yards, but with little success, for their mechanism is somewhat intricate, and a break down in one or more of the drills at once destroys their automatic character; and, further, the class of work for which they are suited is very limited, and their first cost is high.

Art. 500. Side-bar keels are described in Art. 76, and illustrated in Figs. 3 and 7, Plate 85. It is very important that the holes in the three thicknesses (the two side bars and the vertical plate) should be perfectly coincident, for, with rivets so large and long, the staving effect of the hammer blows, and even of a hydraulic machine, is insufficient to ensure the entire cavity of an unfair hole being filled. The holes in the side bars are drilled (if punched they would not be cylindrical), and, to ensure perfect coincidence, the port and starboard bars are clamped together and drilled in one operation. The holes in the vertical plate may be marked by template, to correspond with those in the side bars, but, to eliminate the taper due to the punch, and to correct discrepancies in position, they should be punched at least $\frac{1}{8}$ inch small, and be rimered to size after the three parts are fitted together. As the difference in the labour of rimering every hole and of drilling them is small, it may be found advantageous not to trouble to mark and punch the holes in the vertical plate, but to drill them all (excepting a few *tack* rivets) after the side bars are fitted. When electric drills are available, this is evidently the better course.

The side bars are **marked by a template** in which all the holes are bored, and on which the frame spacing is accurately marked (Fig. 9, Plate 85). It need not be of any particular length, for if shorter than the keel bars it may be applied consecutively. The holes are spaced in fixed relation to the frames, so that the butts of the garboard plates, which must be in the centre of each *clear* frame space, may fall between them (Fig. 7). As, with this type of keel, the frames have no heel pieces, the centre of the clear frame space does not correspond with that of the actual frame space, the former being the distance from the toe of one frame angle to the heel of the other. The butts of the garboard plates are placed in the centre of the clear frame space in order that there may be sufficient room for fitting the straps between the frames, and to secure symmetry in the riveting of the landing edges. As the frames in the fore-body face aft, and those in the after-body forward, the keel rivets in the two bodies are differently disposed with regard to the heels of the frames. The same template, however, may be made to serve for both, by simply marking upon it two sets of frames (distant the breadth of the flange of the frame angle), the one set to be used for marking the holes forward of 'midships, and the other for those abaft it (Fig. 9).

To mark the side bars the template is applied to each one separately, but only to those of one side, port or starboard. Both ends are nicked in for cutting, as shown in Fig. 10, Plate 85 (the precise position of the butts

with regard to the frames is not important), and the position of each frame is also nicked in on the upper edge. The lengths of the various bars, in frame spaces, is seen from the plan of the keel, supplied for the purpose, and the frames, as they are nicked in, may be numbered in accordance with the plan. For drilling purposes the centres of the holes must be dabbed in with a centre-punch. If it is intended to punch the holes in the vertical plate (after marking them by the same template), the dabs made by the centre-punch on the side bars for the drill, must be perfectly concentric with the holes in the template, and this may be readily done by mounting the punch in a plug of wood or metal made to fit the holes in the template (Fig. 8). The holes in the vertical keel plate should also be marked in this way, and, by using a punch with a *finder point* (A, Fig. 8, Plate 52), they may be punched with great accuracy (Art. 305).

Having marked one of the bars, say, No. 9 on the starboard side, as shown in Fig. 10, Plate 85, the corresponding one of the port side is placed underneath it, as shown, with one of its ends between the particular pair of frames indicated on the plan and as nicked in on the upper bar; its other end will, of course, project beyond the upper bar. The two bars are then clamped together, and the frame marks on the upper one, as also its end marks, being nicked across the edge of the lower one, the holes marked on the upper bar are drilled through both. The upper bar is then removed, and the next one adjoining it (No. 10, Fig. 11) having been marked from the template in the same way, is placed on the portion of the lower one not yet drilled, with its end mark coincident with that of the bar just removed, and which has been nicked in for the purpose on the lower one. Its frame marks are then transferred to the lower bar, the other end of which is nicked in for cutting between a certain pair of frames. In this way all the bars are successively drilled, after which their ends are cut. This must be done smoothly and precisely to the line, so that they may butt close upon one another and yet not throw the contiguous bars out of position lengthwise. The best tool for the work is a cold saw, for it makes a smooth cut exactly where required. If cut in a hydraulic or other shearing machine, the ends are rough and uneven, and require to be planed.

Art. 501. The **vertical-plate keel** in connection with a side-bar keel may be marked in the same manner as that in connection with a flat-plate keel (as described in the next paragraph), the only difference being that a template representing the side bars is applied to its lower edge instead of one representing the lower angles. If the plate is to be drilled in place, only the tack rivet holes need be marked. If it is to be punched, the holes should be marked with the plugged centre-punch (Fig. 8, Plate 85), and punched with a finder-point punch, as already noticed. The end joints of the plates are usually lapped, and in such cases the parts in way of the side bars are either tapered in the slotting machine as shown in Fig. 7, or cut away, as shown in Fig. 6, Plate 47.

All the parts of a vertical-plate keel may be **prepared independently by pattern templates.** Those required for marking the keel illustrated in Fig. 5, Plate 85, are shown in Fig. 4. A complete outline template need not be provided for the plates themselves; if there were a large number to be marked (and all were alike) it might be advantageous to make one, but as there are only a few, the detached templates used for the various angle bars may quite well serve the purpose. The procedure of marking one of the plates is illustrated in Fig. 4. In the first place its two edges, and the 2-foot level line (Art. 492), are struck in with a chalk-line; in most cases, of course, only one edge need be sheared. To ensure accuracy in this important lining-off work, the men should not

be required to consult the plan and set off important and constantly recurring measurements with the foot rule, but gauge battens should be provided from the loft. Next, one end of the plate is marked by the template A, which is applied as shown, with its central arm coincident with the level line. The joint, which is a lapped one, falls midway between two frames, the position of one of these being marked across the central arm, and when this frame line is struck square across, and the holes are marked through, the template may be removed.

The templates T and B for the top and bottom angles are now applied coincident with the chalked edges of the plate. These templates do not require to be of any particular length, for, as they are identical from end to end, they may be applied consecutively; for convenience, however, they should be as long as the plate. If one edge of the plate in process of marking does not require to be sheared, it should fall rather within the edge of the template, in which case the precise position of the latter from the level line should be checked by the gauge batten. The longitudinal position of the two templates is determined by the frame line just struck across the plate, with which similar frame marks on the templates should coincide. Vertical lines, representing the frames or floors, are now struck in across the plate, through the frame marks on the two templates, and after the various rivet, drain, and air holes are marked the templates may be removed. The other end of the plate is now marked like the first, the template being so adjusted that the frame marks on its arm are coincident with the floor lines just struck across the plate. The plan is, of course, consulted to ascertain between which particular pairs of frames the ends of the plate fall, and the frames marked upon the plate are numbered accordingly.

The joints of the top and bottom angles fall between two frames, their position being shown on the plan. Each bosom piece must take at least three rivets in the end of each bar (in each flange), and in order that, when thus including in its length the necessary rivets, it may not be more than about 2 feet long, it is usual to space the terminal rivets in each flange of each bar closer together (see C and C^1, Fig. 5, Plate 85). When marking the vertical-keel plate, therefore, a special spacing of the holes is required in every frame space in which the top and bottom angles have a joint, and the necessary modification is readily made, as shown in Fig. 4, by deleting the holes already marked (darkened in the sketch) and applying the small templates C and C^1 to mark suitable fresh ones, the templates being adjusted in position by means of an unmodified hole at either end, which also serves for adjusting them when similarly re-arranging the terminal holes in the bars themselves. It will be noticed that the holes for the upper joint pieces are not in line with the others, but slightly nearer the toe of the bar, which places them in the centre of the clear flange of the bosom piece.

In order to dispense with tapered liners where the fore-and-aft angles cross the lapped joint of the vertical plate, it is usual either to cut the plates as shown in Fig. 6, Plate 47, or taper them away in the slotting machine, as shown in Fig. 5, Plate 85. The last method is the best, for by it the holes in the fore-and-aft angles need not be specially arranged in way of the joints; by the other two methods, they should be arranged clear of the ends of the plates. Tapered liners throw the fore-and-aft bars out of line transversely, and this, in the case of the lower angles, is inadmissible if their holes and those of the flat-plate keel are marked independently, by pattern template (Art. 502).

The holes for the short angles connecting the floor plates to the vertical keel are marked by template D, Fig. 4, Plate 85, the same one being used

for marking the angles; it is applied to the plate with its edge coincident with the chalked frame line, and with its level-line mark (L) coincident with the level line struck on the plate. Where double angles are required, a double template is employed, as shown at E. A special template, having holes at watertight pitch, is employed for marking the holes for the watertight floors, the same one being used for marking the floor angles (Art. 493). The plate is completed by marking the limber holes; these may be punched in every frame space, or wide apart, or only in way of the pump suctions at the after end. A few additional rivet holes are punched in the upper angles (Fig. 5), to act as air holes, unless, of course, the vertical keel is intended to form a watertight division.

All the other plates are marked in the manner just described. If the end joints are butted instead of overlapped, care must be taken in planing them that they be not left "full," for as each plate would then be slightly displaced by its neighbour, the coincidence of their rivet holes with those of contiguous longitudinal parts—not subject to the same displacement—would be spoiled. To ensure accuracy in the marking work, all long templates and battens should be of teak wood, and they should be kept dry; if of pine they are apt to shrink or elongate with the weather, and the holes cannot be bored so truly. Excepting the rivet holes in the overlapped end joints, every rivet is a three-plier, and as the vertical plate is the middle thickness, it does not matter from which side the holes are punched. The rivets in the lapped joints must be punched from the faying surface, and in order that this, in each plate, may be the same for both joints, both ends of every alternate plate should be made to overlap to port, and all these plates be marked on the starboard surface, and all the others on the port (Fig. 5).

The **marking of the top and bottom angles** is a simple affair. There are two templates for the lower angles; one for the vertical flange, just used for marking the vertical plate, and one for the horizontal, which may also be used for marking the flat-plate keel. The length of each bar (in frame spaces) is ascertained from the plan, also the positions of the watertight floors and the joints of the adjoining bars and flat-plate keel; and the holes, as marked from the template, are modified at these places by small supplementary templates, as already described. Care must, of course, be taken when applying the two templates separately to the two flanges that they occupy the proper relative fore-and-aft position, this being determined by a guide nick made anywhere on the heel of the bar. The ends of bars, as delivered from the steel works, are usually rough and ragged, and in order that the bosom pieces and the ends of the bars may fit close, it is well to cut both ends afresh, and, for the reasons just noticed, they must not be left full. In the case of the upper angles, the vertical flanges are marked as just described, but the holes in the horizontal flanges may be spaced by measurement, for the centre strake of tank-top plating is marked by a transferring template. In marking these holes there are several matters to consider; they must be kept clear of the floor plates, so that these may not interfere with the insertion and holding-up of the rivets, they must be specially placed in way of watertight floors, bulkheads, engine and boiler seating, hold pillars, and the end joints of the tank-top plating; very commonly a blank space is left in way of the last two parts, so that suitable holes may be drilled as required later. The procedure of fitting and riveting together the various parts of a vertical-plate keel are described in Art. 509.

Art. 502. Flat-plate keels are described in Art. 77. The different plates being all alike, may be conveniently prepared by means of a pattern

template. Fig. 2, Plate 85, shows the template from which the keel plate shown in Fig. 1 has been marked. The two central rows of holes for the fore-and-aft angles are, of course, identical with those in the template used for marking the angles themselves, and, as already described, they may have to be modified in way of the joints of the latter parts. The three holes in each transverse frame line are punched and countersunk in the keel plate, but it is better to drill them in the frame angles when these are in place; if carefully templated, they may be marked and punched in the 'midship frame angles (along with the other holes, as described in Art. 493), and this is often done, but the sources of error are too numerous for the assurance of good holes. In way of the watertight floors the spacing of the frame rivet holes should be reduced. All plates may be marked, punched, and cut in the flat state, before knuckling. The frame and edge rivet holes of those which rise upwards at the fore-foot must be modified, however, because the lines of the frames (on the plate, when flat) do not stand square with the centre line. The keel plates at the extreme ends, which embrace the inner ends of the stem and stern frame, are not made until these parts are in place. In some cases flat-plate keels do not receive special treatment, but are fitted at a late period, like any other strake of shell plating (Art. 509).

The plates are knuckled to suit the rise-of-floor line, and when this is considerable, the knuckle should be placed close to the toes of the fore-and-aft angles, so as to avoid kneeing the ends of the frames. In the 'midship plates the knuckle is usually so slight as to be negligible; if not, it may be conveniently impressed in the bending rolls, as described in Art. 536. The plates towards the ends require to be more and more sharply knuckled, until they assume a trough-like form. Such plates may be shaped cold in the hydraulic flanging machine, or hot in an old-fashioned garboard flanging machine. One or two of the plates at the fore-foot may also require to be curved fore and aft, as shown in Fig. 3, Plate 83. The fore-and-aft curvature is impressed after the flanging, by heating the plate as a whole, supporting it at either end, and striking it down in the middle with a "dumper," *i.e.* a heavy weight with crossbar attached, which is lifted by manual effort and dropped as shown in Fig. 3. The process causes some alteration in the transverse form, which is corrected subsequently by hammering. To facilitate the shaping operation, keel plates, which have much fore-and-aft curvature, should be narrow, so that the flanges may be shallow; and, for convenience in heating, they should be short.

Art. 503. The **stem** is described in Art. 261. Whether forged or rolled it is delivered in the shipyard as a straight bar, because there is here every facility for bending it, and it is more easily transported when straight. Large stem bars, if made outside, are usually delivered finished, in accordance with a sketch supplied, excepting the drilling of the holes in the curved part, for if the curvature is sharp, the holes here would become oval with the bending. When of rolled steel, the bar is sometimes delivered in the rough, and as it is then parallel throughout, the taper from the load line to the head may be formed by drawing it down under the steam-hammer, the forward edge being rounded at the same time. With rolled stems, however, the taper is usually dispensed with, in which case the edge may be rounded in the plate-planing machine, but this feature is also sometimes dispensed with. The scarph may be blocked out under the steam-hammer and finished by machine, the upper end, or stem-head, being finished as required, to take the mast stays, in the smith's shop. If the stem of a sailing vessel is a forging, the bob-stay and outer-stay lugs are usually blocked out of the solid, if a rolled bar, they are welded on (Fig. 1, Plate 65).

The **stem is heated and bent on the slabs** in the manner described for frames. As a bar so massive is stiff to bend, a chain is attached to its end, and a steam winch employed to pull it round; or, in the absence of a steam winch, the bending rolls, if conveniently placed, may be used; otherwise, a number of men may pull it quickly round by walking away with the fall of an attached tackle. A cut-water stem is bent in two operations. Special care must be taken that the stem lies flat during the cooling, for if not it would not, when erected in place, lie in a fore-and-aft plane. When cold, a bend or twist is not easily remedied; a slight bend may be corrected by striking numerous blows with small hammers on the concave side, which, by expanding the surface metal, causes the whole bar to bend at this part, against—as it were—the hammer blows. A set-iron (in two pieces) may be bent to the shape of the stem in the mould loft (where it is drawn down full size), from which the outline of the stem may be chalked on the bending slabs; in most cases, however, a wood mould is supplied from the loft (Fig. 1, Plate 84).

Care must be taken, when bending the stem, that the scarph at the lower end (if jointed with a bar keel) occupies its proper fore-and-aft position with regard to the upper part, otherwise the vessel would not be of the designed length. The end of the scarph is chalked on the slabs, but the end of the hot bar must be kept beyond it, to allow for shrinkage. The total shrinkage may be determined by noting the expansion that occurs with the heating, by marking with chalk on the slabs the position of both ends of the straight cold bar as it lies in the position it will occupy when about to be bent, and again as it lies in the same position after heating. As it is only the lower half of the stem that is heated, the amount of shrinkage is quite uncertain unless tried in this way. If scarphed, the scarph is usually machined before bending, and to prevent the thin lip from being overheated and burned during the long period necessary for the proper heating of the remainder, it is covered with fire-clay.

After the stem is bent, the holes in the curved part are drilled. They and the others should be arranged to suit the sight edges of the shell plating (Figs. 10 and 11, Plate 93). This is not always done, but if care is taken when sheering in the plate edges, they may generally be kept between the existing holes (Art. 519). In exceptional cases, none of the upper part of the stem is drilled until after the bending, so that the holes may be marked to suit the plate edges, which are transferred to it from the stem mould (Fig. 1, Plate 84). The positions of the frames are nicked in on the lower part, and the direction of a plumb line on the upper, so that when the stem is erected it may be fixed at its proper fore-and-aft inclination, plumb or otherwise; these marks are transferred from the mould-loft floor, by means of the set-iron or stem mould.

CHAPTER XXXVI.

Art. 504. All around the vessel's berth a double row of **stage-poles** or **uprights** must be erected to support the staging required during the work of construction (Fig. 14, Plate 96). Stage-poles may be made as shown in Fig. 11, of fir stems, split up the middle, the two halves being fixed about $3\frac{1}{2}$ inches apart by bolts and short distance pieces; if poles of greater length and strength are required, they are made of hewn timber as shown in Fig. 12. They are fixed erect by planting their ends 5 or 6 feet deep in the ground. The cross **thwarts** or **stage-bearers** may be placed at any required height, by inserting bolts in the stage-poles through holes made for the purpose (Fig. 14). The fore-and-aft distance between the poles should be about 4 feet less than the length of the stage planks—the latter are usually about 16 feet long, of white pine, about 3 inches thick and 11 inches broad. The distance between the two rows of poles depends on the space at disposal in the yard; if there is plenty of room, they may be as far apart as 8 feet, but if there are other vessels close alongside, 4 or 5 feet may suffice. In some cases vessels are built so close together as to permit of only a single row of poles; and sometimes a single row is adopted even when there is room for two rows, the inner ends of the thwarts, in such cases, being supported horizontally by brackets or by links and bolts through the vessel's frames or plating (Fig. 14). The inner row should be at least $2\frac{1}{2}$ feet clear of the vessel's side, otherwise the shell plating could not be conveniently riveted. The poles should extend above the highest point of the hull; a few additional short ones being introduced under the overhanging quarters. Throughout the work of construction, stage planks are placed at whatever height is most convenient for the current operations; as a rule two or three planks, placed between the ship's side and the inner row of poles, form a sufficient stage (Fig. 14). When a new vessel is about to be built, the shipwrights are provided with a plan, giving in figures the extreme breadths and heights of the hull at intervals of about 20 feet, so that the vessel's outline may be staked off on the ground and stage-poles erected to suit; unless the dimensions of the vessel previously built are widely different, only the inner row of poles need be re-arranged. In laying off the various slipways, it is well, if space is limited, to place the vessels in pairs, close together, so that on at least one side of each there may be a wide avenue between the stage-poles for the fore-and-aft conveyance of bulky building material.

Art. 505. The keel blocks having been built up as described in Art. 544, the various **keel bars are laid** upon them, and are faired sideways and held erect by three-cornered ferrings nailed on the blocks and transverse shores, as shown in Fig. 14, Plate 96. The scarphs are then riveted, with tack rivets, and their tops and ends caulked. The **stem** is not put in place until the frames are erected. The **stern-frame** is not always made by this time, but to allow of the aftermost frames being erected, its keel portion may be represented by a log or a plank set on

edge. When, later, it is made, it is usually conveyed to the lower end of the slip on a shallow-draught "scow" or "keel," which may be floated into position at high tide, and then scuttled; to transport so heavy and cumbrous a mass on a trolley over the soft ground between the stage-poles of the various building slips is often impracticable. To lift it from the scow into its berth alongside, a pair of logs are erected as sheer-legs, and a powerful tackle attached. It should be observed that in nearly all shipyards the vessels are built with their stern towards the water; in cases, however, where the river opposite the yard is narrow, the bow is sometimes placed next the water. The latter method is advantageous in that should the vessel, when launched, strike the opposite bank, any damage resulting to the stem will be more readily repaired than damage to the stern-frame, and further, the work of erecting and boring the heavy stern-frame, and building the stern, is more readily done at the accessible upper end of the slip.

Art. 506. The **frames** may be erected immediately the keel is laid. The method of making shallow-floor frames has already been described, all but the final operation of **riveting the component parts together.** This is usually done at the vessel's berth, each frame being put together when lying in a horizontal position over the keel at the upper end of the berth. The aftermost frame is the first dealt with, and as each one is riveted it is hauled down over the keel and erected forthwith in its proper place. During the riveting operation it is essential that the frames should lie in one plane, for any lateral twists or bends would be made permanent by the riveting (Art. 314). To support it, therefore, horizontally, and facilitate the work of bolting the various parts together (this work is done by the frame squad), it is usual to erect temporary fore-and-aft skids, on either side of the keel and level with it, so that while the keel supports the centre of the floor, the skids support either end—the upper ends of the frame may be propped up by shores. The skids are also useful when running the frame down after riveting, for a large frame might bend if supported horizontally at the middle of its floor and upper ends only.

When bolting the different parts of each frame together, the relative positions of the two halves of the floor plate are checked by applying a line to the level-line dabs made upon it at the scrive board (Art. 488). When these are in line the contour of the frame is necessarily correct. At this period the fitting of the heel pieces, tapered liners at the floor-head and the various keelson lugs, is taken in hand, as described in Art. 488. The frames are generally riveted by machine, if by hand, care must be taken that the faying surfaces are properly closed; with the usual wide pitch of 7 diameters this is not always easy, especially at the floor-head and bilge, where the transverse flange of the angles may have crinkled with the bending. When hydraulic riveted, the machine may nip all parts forcibly together (Art. 318).

Art. 507. In the absence of special lifting appliances, such as travelling, overhead cranes or gantrys, or numerous derricks and derrick posts, the **frames are erected** by upright derricks, one on either side of the berth. These are simply long fir poles or logs, to the tops of which the upper blocks of the hoisting tackles are made fast. They are held erect by three guy ropes, and are shifted up or down the berth, a little bit at a time, to suit each frame; an operation which is facilitated by stepping them on a flat sole piece, or skid. The frames of small vessels may be erected by hand winch, but most yards are provided with a portable steam winch and attached donkey boiler, hydraulic derricks, or electric winches, which may be employed for all heavy hauling and hoisting work. These appliances may be placed anywhere alongside, or at the upper end of the vessel's berth,

the falls of the hoisting tackles—which are of wire to avoid chafing—being led round corners, as required, through snatch blocks fixed to the heels of the stage-poles. The hoisting tackles being made fast to either side of the frame (one built complete, with shallow floor), it is gradually canted upwards, with its heel resting on the keel. When hoisting large, heavy frames, the tackles should not be allowed to "surge" violently (when the fall shifts on the warping end of the winch), for the jerk, when the frame is lying horizontally, is apt to bend it. The upper-deck beams should be erected concurrently with their frames, while the derricks are still in position; those of the lower deck may be erected subsequently, the upper-deck beams being used as points of suspension for the hoisting tackles. In small vessels the beams may be bolted to the frames before the latter are erected, so that both may be hoisted together; a long beam, however, especially if it has a narrow top flange, is apt to bend if lifted when lying on its side, for in this direction it is weak and flexible. The heels of the frames are fixed over their marks on the keel with bent plate-washers, and by *toms*, or distance pieces, between the frames, as shown in Fig. 9, Plate 96.

When the aftermost frame (or one forward of it) is erected, it is supported on either side by a long shore, whose head is fixed against it by a bolt through one of the rivet holes (Fig. 13, Plate 96). To prevent the frame from falling forward or aft, guys of chain or wire rope are led fore and aft from its upper end and made fast to the heels of convenient stage-poles, rigging screws being introduced to adjust the tension. By setting up the shores and tightening or slackening the guys, it is then possible to adjust the frame in every direction. In doing this there are three conditions to observe (1) the frame must be plumb transversely, *i.e.* the centre of the beam must be exactly over the keel; (2) it must be square across the keel; (3) it must be perpendicular to it, *i.e.* it must not lean forward or aft. The first condition is secured by suspending a plumb line from the centre nick on the beam, and setting up the port or starboard shore until it falls over the centre of the keel. The second may be obtained by suspending a plumb line from each gunwale, and sighting them across the keel, until they are in winding with the edge of a large square held on the side of the keel, the necessary adjustment being made by tightening or slackening the rigging screws on the guys. This operation is referred to as "horning" the frames. The third condition may be secured by stretching a line across the frame from gunwale to gunwale, and, from the centre of this line, another down to the heel of the frame at the keel; the latter line, which of necessity is in the transverse plane of the frame, may then be plumbed with the top of the keel by a large square. Instead of using a large square, the plumb line shown, Fig. 4, may be employed; this is specially designed to allow for the declivity of the vessel's keel, for as the two lines LL are drawn at an angle with the edges of the board equal to this declivity, it follows that, when the hanging plumb line coincides with one or the other, the edges of the board are necessarily square fore and aft with the keel.

Previously to erecting the frames, their spacing is marked off on the various **ribbands**, as described in Art. 480, and the gunwale ribband is suspended aloft from the stage-poles, conveniently for fixing to the frames. When the first frame is erected and shored, the ribband on either side is fixed to it at its mark (there is a mark on the frame as well as on the ribband), and as the others are erected, they also are fixed to the ribband (Fig. 13, Plate 96). The ribbands thus serve to hold the frames at fixed distance, so that the adjustment of one of them, square with the keel, serves to adjust them all. The necessary transverse support is given by shores,

which are placed one at every fourth or fifth frame. The ribbands not only hold the frames at fixed distance, but impart in some degree the characteristics of a continuous structure, so that the supporting and fairing effect of individual shores may be distributed over a number of otherwise independent frames.

Ribbands are usually of yellow pine, 40 or 50 feet long, and from 4 to 6 inches square, according to the stiffness and massiveness of the frames; the stouter they are, the more likely are they to pull the frames quite fair, and the greater the rigidity and continuity imparted to the structure. Those which are sharply curved at the bow and stern are of elm, tapered towards one end. The side which fays on the frames should, of course, be fair and regular. They are connected to the frames by clamp plates, termed "plate" or "long washers," as shown in Fig. 10, Plate 96; this mode of connection permits of the frame (and ribband) being adjusted to its mark, after it is screwed up, by simply striking it forward or aft with a hammer. The same ribbands serve for many vessels, new holes being bored where necessary to suit the new frame marks. Their ends are usually butted and jointed by clamp plates, otherwise they may be scarphed (Fig. 10). The ribbands used for fairing the deck beams, etc., are sometimes made as shown in Fig. 6, Plate 97, this formation avoiding the necessity of boring holes, and facilitating the work of fixing the ribbands.

No special effort is made **to fair the frames** until a considerable number are erected. The bilge and side ribbands are then put in place, and the transverse bulkheads, if prepared in the shed, are also erected. As the various frames are erected, their upright condition is checked by plumb lines suspended from the centres of the beams (Fig. 14, Plate 96). As a rule only one frame need be horned and held by fore-and-aft guys, but the squareness of the others (across the keel and fore-and-aft) is checked at intervals. If the frames and bulkheads are properly made, the fixture of the various ribbands should result in a perfectly fair outer surface. The shell flange of the frame angles should lie close to the ribbands; if only the toe touches it, the frame should be twisted in such a way as to bring the heel close, by tomming the frame off from the adjacent one, as shown in Fig. 10; if this be not done before the side stringers and shell plating are fitted, it may be difficult to secure proper contact between the frame and shell without the use of objectionable knife-edged liners (Fig. 18, Plate 93). Care in this respect is particularly necessary in the case of deep, solid frames, for, being very rigid, the shell rivets may be quite incapable of twisting them fair and pulling the heel close to the shell.

The condition of the frames when faired, ribbanded, and shored, is shown in Figs. 6 and 14, Plate 96. The number of ribbands varies with the size of the vessel. The **shores** are placed at every fourth or fifth frame; those under the lower bilge ribband are required to support the weight of the frame and beam; in their absence, the midship frames of a large vessel (having shallow floors) might bend downwards at either bilge. They are not removed until an adjacent strake of shell plating is fitted, when they are transferred to it and the ribband removed for the fitting of the next strake; the various ribbands are, of course, placed in way of the outer strakes. The side ribbands may be removed whenever the side stringers are riveted to the frames. The gunwale ribband and shores may be removed when the deck stringer is in place; the shores need not be replaced. During the remaining period of the vessel's construction, when her weight is constantly increasing, she is kept erect, and the keel blocks relieved of some weight by two or three rows of stout shores, placed

underneath the bilge and flat of the bottom, and by **bilge blocks** (see Figs. 3 and 5). The latter may be described as substantial pedestals, composed of wooden blocks and planks arranged athwartship and fore and aft, wedges being driven between the upper pieces to adjust the pressure, as in Fig. 3; or the upper pieces may be wedge-shaped, as in Fig. 5. In a vessel of moderate size there may be three or four bilge blocks on each side, and they should be placed below the transverse bulkheads. As they are perfectly stable and solid, they ensure the vessel sitting upright, almost independently of the numerous unstable shores. On the north-east coast of England, where the keel blocks are not very substantial, numerous small bilge blocks are employed, spaced, about 25 feet apart, all fore and aft. When there are only a few bilge blocks, they must be adjusted with special care, for should any subsidence of the ground occur, they may cause undue local pressure and deformation of the hull. In the building of a large vessel, shipwrights are told off for the sole duty of adjusting the numerous shores and blocks, so that, at all times, all may take approximately the same pressure. Keel blocks are described in Art. 544.

Art. 508. The surface of the **upper-deck beams** is **faired** immediately after the ribbanding and fairing of the frames; for which purpose fore-and-aft ribbands are fixed on their upper surface, one on either side of the hatchways, so that they may support the inner ends of the half-beams (Fig. 14, Plate 96, and Figs. 5, 6, and 7, Plate 97). In the absence of pillars, the beams are supported by shores, which are placed with their heels on the floors (on a stage plank or strake of tank-top plating) and their heads under the beams, a plank being introduced as required, to distribute their supporting effect (Figs. 5, 6, and 7, Plate 97). The heads of the shores should be tied with rope or wire, so that should they loosen they may not fall and injure the men. The beams, being flexible, may be set up several inches by the shores; to ensure, therefore, that they are at their proper height, and that the deck surface is fair as a whole, a batten is provided from the loft, giving the height of each beam above the top of the keel. By this time the bulkheads should be in place, and as they form fixed points in the deck surface, the beams must be faired up or down to suit them. If the various parts of a vessel's framework were prepared with absolute precision, the fairing of the framework, when erected and put together, would be a simple affair, for all parts would fall naturally into their proper place; in ordinary shipyard operations, however, there are many sources of error, resulting in small discrepancies, some in one direction and some in another, and consequently, when adjusting the various parts, judicious compromises must be made.

The central part of the beams, having been faired and supported by shores, their ends at the gunwales are next dealt with. A long sheering batten, say 3 inches broad, is first applied to the outside of the frames (Fig. 1, Plate 96) with its upper edge level with the tops of the bulkheads (if these are erected), and with as many of the beams as is consistent with a fair sheer line (a large number will be found to be above and below it by $\frac{1}{2}$ inch more or less); its lower edge is then marked on the frames—its upper one cannot, for it stands above them. Beginning now from aft, any beam that requires adjustment is fixed to its frame by a screw clamp as shown in Fig. 1 (or by a long washer below the knee), the bolts in the knee are withdrawn, and the beam struck up or down with a hammer until its top is 3 inches above the batten mark on the frame, a condition determined by means of a gauge, as shown. At this period there are only two holes in the beam knees, and, of course, the adjustment of the beam spoils their coincidence (they may become half blind or wholly blind); but the remaining holes may

now be drilled, and the two unfair ones rimered to a larger size. Very commonly the latter are so unfair that they cannot be even approximately corrected by rimering, in which case it is better to drill one or two fresh holes. To expedite the work, it is usual, as each beam is faired, to drill only one or two holes in each knee, for then all the beams may be quickly faired and bolted, the remaining holes being drilled at leisure. This work is undertaken by shipwrights, with two or three drillers in attendance.

In some shipyards, to avoid bad holes in the beam knees, all are drilled after erection, the beams being held temporarily in position by clamps, and long washers below the ends of the knees. The beams of small vessels are sometimes riveted to the frames before erection, in which case, to ensure a fair deck and side, the holes in the beam knees should be marked from the frames as they lie on the scrive board. While fairing the beam ends up or down, attention should be given to the fairness of the upper parts of the frames; if these should be seen to be too far in or out (by running the eye along the gunwale ribband, Fig. 1, Plate 96), they should be adjusted where practicable, before drilling the beam knees. As a rule, the tops of the frames are never quite fair, so that tapered liners of various thicknesses must be introduced between them and the sheer strake. If the coaming lugs are already riveted on the ends of the half-beams at the sides of the hatchways, they must be kept in line when drilling the holes in the knees, a condition readily secured by bolting a fore-and-aft ribband on the lugs. In many yards the beams are not faired until the deck stringer is fitted on their ends, which procedure has the advantage of allowing the upper ends of the frames to be properly faired, inwards or outwards.

Art. 509. Consider, now, the method of **erecting the framework of a vessel having a double bottom**, such as that shown in Fig. 6, Plate 96, the various parts of which have been prepared as described in Arts. 492 to 494. The **flat-plate keel**, when deposited on the blocks, are faired laterally by the centre-of-keel marks on the sides of the latter (Art. 544). The fore-and-aft angles are then bolted in place, the position of the various lengths being ascertained from the plan, after which the **vertical-keel plates** may be erected, one of the two angles being loosely bolted to facilitate their insertion between them. In the absence of special lifting appliances, the plates may be lifted and canted into position by a body of labourers, but if very heavy, small sheer legs must be erected. When the vertical-keel plates are in place, their top angles are fitted. If the various parts have been properly prepared (Art. 502), all should fall naturally into place, with close joints and fair holes throughout. The fairness of the keel, fore and aft, may be checked by stretching a wire from end to end, alongside of the lower angles. The vertical plate is held upright by side shores; it need not be plumbed, for the subsequent fitting of the floors does this. The vertical connecting lugs and the various buttstraps and bosom pieces are now prepared, after which the entire keel structure may be riveted, which work, if the keel is long and of heavy scantlings, may be advantageously done by machine. In many yards the flat-plate keel is fitted with the rest of the shell, at a late period, when the structure is sufficiently rigid to permit of the removal of the keel blocks (in groups); in such a case the vertical keel, with its lower angles, is laid directly on the blocks, or a deck plank may be interposed. This method is advantageous in many respects.

Immediately the keel is riveted, the floor plates may be erected. In many cases the vertical angles for the connection to the keel are riveted to them (instead of to the vertical keel) before erection (Art. 493). If expedition is important, the 'midship floors should be put in place first, so

that the work of erection may proceed forward and aft simultaneously. When three or four floors are erected on either side, they form a platform for the erection of the remainder, this work being conveniently done by a small derrick with hand winch, bolted to a couple of stage planks fixed to the reverse bars, and which may be shifted along as required. As each floor is bolted to the vertical keel, the adjoining intercostal plates, if riveted up complete with their connecting angles, or if flanged to the floors, should be fitted, otherwise difficulty may be experienced in inserting them subsequently between the floors. To hold the floors together and permit of their being properly shored and faired, two ribbands are placed near their ends, a stout one on the shell surface and a lighter one on the tank top (Fig. 7, Plate 96); and to hold them square with the keel (a condition which may be checked by the application of a large square) a couple of fore-and-aft shores are fixed to the ribband, as shown in Fig. 8. When the margin plates are made by pattern template, as noticed in Art. 515, fairing ribbands are not required. If the tank top is a level surface, the floor ends are shored up or down until a spirit level, placed on an athwartship straight edge, indicates the horizontal; if it slopes, the level lines dabbed on the floors may be employed as a base. If the floors have been accurately made, then, when the tank-top surface is fair, the shell surface must also be fair; small discrepancies, however, are unavoidable, and where they occur the fairness of the shell surface should have precedence over that of the tank top, irregularities in the latter being unimportant.

When the floors, or a portion of them, are erected and faired, they may be riveted to the vertical-keel and intercostal plates. In large vessels, having heavy scantlings, machine riveters are sometimes employed for this work, in which case, in the absence of a travelling gantry or overhead crane, the machines may be mounted on trolleys running on rails, laid on the ground or tank top. Machine riveting is particularly suitable for this work, for when done by hand it is slow and costly, and not always satisfactory, because, owing to the confined spaces between the floors, it is single-handed work, *i.e.* only one man can strike the rivets, and he cannot always strike a good blow.

Immediately the floors, or a portion of them, are faired, the margin plates (if not already made and fitted as noticed in Art. 515) are taken in hand, for until they are fitted the side frames cannot be erected. In most cases, the short margin connecting angles, or lugs, on the outer ends of the floors are riveted thereto before the floors are erected; sometimes, however, they are not, in which case, to secure a fair surface for the margin plate, two fore-and-aft sheering battens are placed, one on the ends of the reverse bars, and the other on the ends of the frames, with their outer edges in a fair curve, and flush with, or rather beyond the outer edges of the floors (or the battens may be fixed on the ends of the floors); so that when the angles are put in place to mark the holes, they may be adjusted fair with the battens. The work of making the margin plate is described in Art. 515, and when it is fitted in place the fitting of the tank-top or shell plating may be proceeded with.

Art. 510. On the north-east coast of England the **bottom shell plating** is fitted before the **tank top**, elsewhere the tank-top plating is usually fitted first. The former method is advantageous in that, owing to the greater accessibility, the work of fitting and riveting the important shell plating is more conveniently and easily performed, and so is more likely to be satisfactory. The subsequent riveting of the light tank-top plating is facilitated (as regards the holding up of the rivets) by leaving every second strake off until the others are riveted, and then riveting the former plate

by plate, so as to give ready access to the tank. Very commonly the fitting of the intercostal plates is also deferred until the shell is in place, for the latter then serves as a convenient platform for the work. The other method, of fitting the tank-top plating before the shell, is advantageous in that the tank-top rivets may be conveniently held up by a man standing erect between the floors, the subsequent holding-up of the shell rivets, in the confined space of the tank, being comparatively easy, due to the fact that the force of gravity assists the hammer. Further, the tank-top plates are more easily put in place, owing to the absence, at this period, of the side frames; and the tank top, when plated, forms a good working platform and permits of the bulkheads being erected and other structural work proceeded with. It should be observed, however, that in yards where the tank top is not fitted until after the shell plating, provision is made for the early erection of the transverse bulkheads, by fitting a special **transverse** strake of tank-top plating in way of each one (Plate 88).

When the margin plate is in place the **side frames** may be **erected.** Their short connecting angles are usually riveted to the margin plate before they are erected (Fig. 6, Plate 84), so that they may be bolted or clamped to them forthwith. If prepared as described in Art. 494, the rivet holes in both the lugs and the frame brackets are punched to correspond, if not, the holes in one of the parts must be drilled. In some cases, to avoid drilling these holes, the frames are secured in place temporarily by lugs or long washers, as shown in Fig. 2, Plate 96, until the connecting angles are marked, punched, and fitted in place. In any case, of course, the lower ends of the frames are supported and held more or less rigidly by a stout ribband and numerous shores, so that individual frames are not entirely dependent on their temporary fixture by lugs or long washers.

The aftermost frames are usually the first put in place, but if expedition is required, the 'midship ones are erected first, for then the work of erection may proceed simultaneously forward and aft. Each side frame and upper-deck beam must, of course, be lifted separately, so that, compared with the erection of shallow-floor frames, the work is slow. Sometimes the beams are not put in place until all of the frames are erected and secured to the margin plate; and in order that, in their absence, the frames may be faired, long planks, upon which the deck breadths are set off from the loft, are fitted at intervals from frame head to frame head; this procedure must sometimes be followed owing to the non-delivery of the beams from the steel works. When a number of side frames are in place, they are faired in a similar way to that described for ordinary frames; but greater care is required, for owing to their severance at the margin plate, and the imperfect and unrigid character of the temporary bolt connection thereto, they have no natural tendency to fall into their proper positions. If the transverse bulkheads are already made, they should be put in place before the frames are finally faired. When faired, shored, and ribbanded, the side frames should form a fair and continuous surface with those within the tank; and when this condition is secured, the lugs connecting them to the tank margin plate may be riveted, which operation at once imparts rigidity to the entire framework and permits of other structural work being proceeded with.

Art. 511. By the ordinary building procedure the **beams,** however soon they may be made, are not required until the frames are in course of erection, which operation, in the case of a vessel having a cellular double bottom, may not take place for some weeks after the first delivery of material. Sometimes, therefore, when great expedition is required, or

when it is desired to keep a large number of workmen employed, the upper-deck beams are made at an early period, but, instead of putting them aside to await the erection of the frames, they are **laid in a vacant berth,** upon suitably arranged blocks and fore-and-aft logs, where they are ribbanded, shored, and faired, all at the proper spacing and relative height, in such a way that the deck surface so formed has precisely the sheer it will have when the beams are erected in the ship. The beams are faired, of course, by means of height battens from the loft and a fore-and-aft base line marked off on the blocks underneath, the centre nicks on the beams being placed in one straight line all fore and aft. When so arranged the whole of the deck plating may be prepared, as also the hatchways, deck houses, casings, etc., so that all may be ready for riveting in place immediately the beams are erected in the ship.

Art. 512. The **side stringers and keelsons** must be fitted immediately the frames are erected and faired, so that the framework may be bound as one piece independently of the temporary wooden ribbands. Before proceeding to fit them, their precise line must be sheered in (with a batten, or chalk line), so as to pass fairly between each pair of holes in the reverse bars and lugs. In most cases, however, to ensure fair stringers and well-placed holes, the holes are beared after the stringers are lined off, or the fitting of the lugs themselves may be deferred.

The following is the usual procedure of making an I-section, **centre keelson,** such as that illustrated in Fig. 1, Plate 47, and Plate 101. Firstly, one of the lower angles is fitted in place, for the whole or a portion of the vessel's length; the holes in the reverse frame and lugs being transferred to it by a batten template, one edge of which is placed half the thickness of the vertical plate from the centre line—previously struck in with chalk. The holes in its vertical flange are spaced by measurement, six being placed rather closer together in way of the joints of the other angle, and four in way of the joints of the vertical plate (if butted, as in Fig. 3, Plate 47). A plan is, of course, provided showing the position of the various joints, and other features affecting the construction. Where watertight bulkheads are pierced, holes should be suitably placed in each flange to take the collar angle (Fig. 13, Plate 55).

The first lower angle being screwed up in place, the second is templated from it. The same template serves for marking both flanges, for, having been applied to the vertical flange of the bar now in place, it is canted down, without shifting it longitudinally, to mark the holes in the lugs and reverse frames. It should be long enough to include a complete vertical plate as well as the angle, for then it serves to mark both parts. If one of the vertical plates is already in place, the position of its end is noted for the preparation of the next, by nailing a short upright piece to the batten template, to cover its rivet holes if the joint is overlapped, or to touch its end if butted. The holes in the upper edge of the vertical plate are spaced by measurement, observing, as before, to place them suitably in way of the watertight bulkheads and joints of the angle bars.

When the vertical plates are in place, the upper angles are templated from them. The same template serves for marking the vertical flanges of both top angles, but as the holes are, of course, only marked on one side of it, it follows that while they are uppermost when it is applied to one of the angles, they are underneath and out of sight when applied to the other. In the latter case they may be marked either by hammering the template against the bar, so that the whiting marks may leave an impression, or if, as is usual, they have been transferred to the first by driving a centre punch through the wood, the small perforations serve to locate the holes for

similarly marking the second. The holes in the horizontal flanges, for the covering plate, are spaced by measurement; those in way of the joints of the latter should be placed rather closer together, and, if the flanges are wide, in two rows; and a blank space should be left in way of the heels of the hold pillars, *i.e.* at every second frame, for these should be drilled subsequently, through holes already drilled in the pillars. When the upper angles are bolted tightly in place, the covering plate may be fitted; this, and the fitting of the buttstraps, does not require special notice.

In making a **side, intercostal keelson,** such as that illustrated in Fig. 14, Plate 89, one of the bars is first screwed down in place, then the intercostal plates are fitted, and subsequently the second bar. The intercostal plates may be conveniently made by means of two boards, cut out in the manner indicated at A, Fig. 14. These are fitted in the frame space as shown, and when the holes in the keelson angle, and the position of the heels of the two frames are marked, the triangular notch on one board—being pencilled on the other—permits of the boards being put together, exactly as before, when laid upon the plate. Each pair of boards may be used simultaneously for the corresponding plates on both sides of the ship (the marks being made on both surfaces), and successively for a large number. The edges of the plates, having no connection to the floors, must be carefully sheared, so as to bear upon them, the triangular notches in way of the reverse bars are usually cut out by punching consecutive rivet holes, but the tool described in Art. 534 does the work quicker and better. If the keelson falls over an inner strake of shell, the outer edges of the intercostal plates must be cut slightly within the frame marks; if over an outer strake, about $\frac{1}{4}$ inch beyond. If the frame spacing is less than 29 inches, four holes are punched in the lower edge for the shell angle; otherwise five are required. A limber hole is usually punched as shown in Fig. 14, the triangular opening at one corner serving to pass drainage water. One edge of the plate often fouls one of the frame rivet heads, in which case it must be notched; this may be avoided by keeping all rivet holes clear of the lines of intercostal plates when marking the frame bars (Art. 486).

After the intercostal keelson or side stringer (as also the deck stringer plates) is riveted, the **shell angles or lugs** may be fitted and riveted. Very commonly this is deferred until the shell plating is in place, but this involves extra fitting work and awkward riveting. When fitted previously, care must, of course, be taken so to place the angles that they shall fay with precision on the shell plating, so as to touch, without displacing it. If the keelson or stringer falls over an inner strake of shell, then, of course, the angles must be kept flush with the shell flanges of the frames, but if over an outer strake, they must project beyond, by the thickness of the plating; with joggled plating, all must be flush with the frames. Perfect accuracy may be ensured by using the gauge shown in Fig. 14, Plate 89. This is applied not only when marking the angles (they should be marked by applying each one in place), but subsequently to check their position when screwed up ready for riveting, *and after* riveting. Where the thickness of the shell plating varies, different gauges must be used. As the intercostal plates of a side keelson stand square to the tops of the floors, they do not, owing to the rise of floor, stand square to the shell; if the divergence is considerable, the shell angles must be bevelled, but, as a rule, the bevel is so small as to be negligible.

Art. 513. In the case of the **side stringers,** many of the bars are more or less curved. If the curvature is slight, the bars may be sufficiently flexible to be pulled into position without preliminary bending; if considerable, or if the bars are of rigid section, each one must be bent approximately

to shape, in which case the required curvature is ascertained either by stretching a line from end to end of its berth and noting the departure from the straight, or by making a rough mould. In the case of an intercostal stringer, this mould serves also as a template for preparing the intercostal plates (see Fig. 13, Plate 89). The latter are fitted in long lengths, notched at each frame, and the position of the notches, and the angle at which they must be cut, may be noted on the template. If the intercostal plates are narrow they are ordered in parallel lengths, and are bent to shape; if the curvature is small, they may be bent cold in the beam bender, and if this should cause them to buckle, they may be straightened in the mangle. To facilitate the bending, they are sometimes bent after notching, but as the deformation is then concentrated at the reduced parts in way of the notches, it may cause undue local stress in the steel. When the curvature is considerable, the plates require to be heated, but in such case, or when the plates are wide, it is usually better to order them sufficiently broad to cut to shape.

The notches are usually cut by punching a series of contiguous rivet holes. Some shipyards are equipped with a punching machine specially arranged for punching rectangular notches. The notches should not be longer (fore and aft) than is necessary to clear the reverse bar or lug; very commonly they are made too long, which reduces unnecessarily the length of the shell lugs. The holes for the latter must be punched from the faying surface, *i.e.* from above or below, according as the angles are fitted above or below; sometimes they are wrongly punched, with the result of unsound rivets, which readily loosen under stress. Lloyd's rules require four rivets in each flange of the lugs when the frame spacing is less than 29 inches, otherwise five are required. The lugs are usually placed above, for they are then more easily fitted and riveted; but if, when so placed, they would foul a shell landing, they are reversed. When a shell landing traverses an intercostal stringer or keelson, it is a difficult matter to secure good rivets, and, accordingly, such crossings should be avoided when arranging the structural design. Where the heads of landing rivets would foul the stringer lugs, they should be flush countersunk; and the lugs may be made with an extra wide flange, to clear the rivets if necessary. The joints of the intercostal plates are not usually strapped; and though the angles may run through the transverse bulkheads, the plates are usually stopped, so as to avoid the necessity of cutting a deep score to pass them through. When the stringers are formed of a single large angle bar and intercostal plate, as in the alternative arrangement in Plate 105, the joints of the intercostal plate are strapped.

In the case of the **wide, hold stringer** shown in Plate 102, the supporting bracket plates may be hydraulic riveted to the frames, complete in every respect before these are erected; but as their upper edges are then seldom fair with one another, it is better, in order to secure a fair stringer, to defer the riveting of their upper angles until the frames are in place; a couple of lines may then be stretched fore and aft, touching, or nearly touching, the top edges of the bracket plates, to serve as a guide when fitting the angles. The stringer plates are templated as described for deck stringer plates; if they pierce the transverse bulkheads, a wide score must be made in the latter, so that the plate may be passed through with its notched part clear of the bulkhead shell angles and the frames beyond (Fig. 11, Plate 55). When arranging the lengths of parts which require to be reeved through bulkheads, care must be taken that they may clear the existing web frames and other obstructions when it is required to fit them in place.

Art. 514. Special bars should be provided for cutting up into **bosom pieces,** having at least the same thickness as those it is intended to connect, but flanges $\frac{1}{2}$ inch narrower. Their heels are usually removed in the plate planing machine, for although bars may be rolled for the purpose, with rounded heels, they are not readily obtained in small quantities; to avoid unnecessary labour, however, it is well that bars of this description, of standard sizes, should be kept in stock. To secure a proper caulk in bosom pieces of watertight work, such as gunwale bars, the rounded toe must be removed; in such cases, therefore, it is common to use bars of the same scantlings as those connected, and shear about $\frac{1}{2}$ inch off the toes, the sheared edge being sufficiently sharp and square for caulking purposes; otherwise the toe of a small bar may be planed, but unless the special machine described in Art. 323 is available, this involves extra labour and loss of time. The holes provided in the ends of the bars for the bosom piece should not be punched in the centres of their flanges, but rather nearer the toe, so that they may fall in the centres of the flanges of the bosom piece. And the ends of the bars should be smoothly cut; very commonly the rag left by the hot saw at the steel works is not removed, in which case the bosom piece cannot be fitted close. The work of fitting bosom pieces is generally entrusted to lads or unskilful workmen, and, consequently, it is often badly done.

Art. 515. The **tank margin plates** may be flanged first and cut and punched afterwards, or *vice versâ*. The flanging is usually deferred until the floors are erected, but it may be undertaken at any time, from bevels taken from the scrive board, and it is advantageous to do it at an early period, so that the plates may be fitted without delay, immediately the tank frames are erected. They may be flanged either hot or cold, as described for garboard plates (Art. 521). The precise radius of the knuckle is unimportant, but in way of watertight floors it should, of course, conform with the corner of the watertight angle frame, if this is already made. The plates amidships are straight fore and aft, but those towards the ends, if not arranged as described in Art. 193, are more or less curved. The required curvature may be obtained from the scrive board, by setting off the breadths there given at each frame and running a curve; if the curvature is considerable, a set-iron should be bent to check the form of the plates, but very commonly only the deflection from the straight is noted. The curvature is usually small, and is impressed by heating the plate, supporting it at either end, and striking the flange down with large hammers; or one end of the hot plate may be lifted and dropped, so that its middle part may sag downwards between the supports; the bending tends to distort the flange, which is faired subsequently by hammering. Very commonly the plates are improperly bent, in which case the pulling of them into place, by screw bolts, causes the flange to buckle up and the flat surface to become hollow transversely, due to the fact that the flange does not bend longitudinally with the remainder. Such deformation is made good by fitting liners between the plate and the floor-end lugs; but these are very objectionable, for the connecting rivets, whose soundness is very important, may then be four-pliers. In arranging the tank-top plating and margin plates, it is well, when the latter are not straight fore and aft, that their flange should be as narrow as practicable, to facilitate the fore-and-aft bending.

The margin plates, when flanged, may be templated immediately the floors are erected; there are, of course, only the cross rows of rivets to transfer. Very commonly, when the flange has no fore-and-aft curvature, they are templated in the flat before flanging; when a cold-flanging machine is available this is an easy matter. The templating of a

plate already flanged is done in the manner described for garboard plates in Art. 521. If the plate has fore-and-aft curvature, special care must be taken in applying the template to the flange or tank-top portion, to allow for any discrepancy in its fore-and-aft curvature. When the flange is so narrow as only to take one or two rivets in the end of each reverse bar, the work of fitting the plate is greatly facilitated if, instead of punching these holes in the reverse bars, they are drilled subsequently through holes suitably punched in the margin plates, or they may be punched in the reverse bars and drilled through the margin plate; and this procedure has the advantage of ensuring good holes, for in most cases, when they are punched in both parts, they are unfair. When the one margin plate overlaps the end of the other, care must be taken to secure a proper fit at the knuckle, the radius of the knuckle of the overlapping plate being made rather greater than that of the other. To bring the two plates close at the knuckle, a rivet hole is usually drilled at this point. The end of a plate already flanged is not readily cut; only one end need be cut, however, to do which it is sheared as close to the knuckle as practicable, the knuckle portion being removed by punching consecutive rivet holes; afterwards it may be planed for caulking, but as the knuckle portion must be hand chipped, it is usually found more convenient to chip the whole. The end joints are sometimes butted and strapped, in which case the straps (if single) are usually placed on the inside, being flanged like the plate, so as to cover the entire joint; if placed outside, their lower ends are not easily caulked. The lower edge of the margin plate should, of course, be cut sufficiently back to clear the shell. The holes along either edge should be marked on the outer or faying surface; they are spaced 4 diameters apart, keeping them clear of the floor ends. For the proper fixture of the lugs which connect the side frames to the margin plate, the lines of the floor ends must be nicked in on the outer surface of the latter, for which purpose they are marked on the template at the ship, and transferred thence to the plate. In some yards the margin plates are made complete from pattern templates provided from the loft, the lugs on the floor ends being also punched to correspond, so that immediately the floors are erected, the margin plates may be screwed up in place. When this procedure is adopted the side of the double bottom is usually designed to form three straight lines in plan, as shown in Fig. 3, Plate 89.

Art. 516. The **margin-plate shell angle** should be fitted immediately the plate is screwed up in place. It is essential that it should be fair with the surface of the contiguous tank frames, otherwise it would show as a ridge or depression on the outside plating; in many cases, through careless fitting, the line of the margin plate is clearly discernible. Fairness may be readily secured by employing a long batten template having a straight outer edge, and so adjusting it that its edge is fair fore and aft, and, at the same time, flush with the ends of the tank frames; a few of the latter may lie slightly within it, in which case they must be linered when fitting the shell. If it is intended to punch the corresponding holes in the frame brackets and margin-plate connecting angles (in the manner described in Art. 494), then, before removing the batten template, the 12-inch gauge line must be chalked on the surface of the margin plate, parallel to its outer edge. Where the margin plate falls on an outer strake of shell, the angle bar should, of course, project beyond the heels of the tank frames by the thickness of the plating; and, towards the ends, where it may leave an inner strake and pass on to an outer one, it may be joggled, or a tapered or parallel liner fitted between it and the shell.

When the **shell landings cross the margin plate** they do so

obliquely, and, consequently, the two rows of landing rivets are alternately too near the heel, and too near the toe of the margin angle. This is usually avoided, to some extent, by cutting the edge of the inner strake as shown in Fig. 5, Plate 89, and sometimes also by enlarging the flange of the margin angle, as shown in Fig. 4. But it will be observed that some of the shell rivets are still too near the throat or toe of the shell angle and the caulking edge of the shell plating, and, in such cases, tap rivets, screwed in from the outside, must be substituted. The best plan of avoiding the above difficulty, and one which is adopted in high-class vessels, is to alter the line of the entire shell landing where it approaches the margin plate, as shown in Figs. 6 and 7. It will be observed that the shell landing, after it has crossed the margin plate, may either be brought back to its original line (Fig. 7), or be continued in its new one (Fig. 6). The method of making the margin shell angle is the same as that described for gunwale bars. Joint pieces are sometimes dispensed with in this angle; if fitted, they are placed on the inside of the margin plate (Fig. 6), for this position avoids some three-pliers, and the joint is more easily caulked. Tapered liners are usually introduced where the margin angle crosses the lapped joints of the shell, otherwise the ends of the inner-lapping shell plate may be tapered in way of the angle.

Art. 517. When the frames and beams are faired, the **deck plating** may be proceeded with. The stringer plates are the first dealt with, for when they are in place the gunwale ribbands, which till then have served to hold the frames fair and at the proper distance, may be removed. The position of the various plate landings and the true centres of the beams are first lined off on the latter, by a loftsman or shipwright, in accordance with the plan and with the ordered dimensions of the plates; sometimes the landings are already nicked in on the beams, and if the holes are not already punched, they must now be beared. The position of the fore-and-aft angles of deck houses, etc., should also be marked on the beams, to assist the platers in marking the necessary lines of rivets on the plates. A working plan is, of course, provided for each deck, showing every feature affecting the plating, and giving figured dimensions for all distances and sizes. Such a plan is shown in Plate 86, but the dimensions are not all given.

A template such as is used for an **upper-deck stringer plate** is shown in Fig. 16, Plate 89. It will be observed that little attempt is made to shape it precisely to the outline of the plate, for this may be noted more quickly and easily by pencil marks or spilings. The only requirement is that it shall cover all beam holes; and it is usually preferable that it should fall rather within the boundary lines of the plate, for it is easier to note spilings than to transfer marks, which themselves may be covered by the template. All marks and spiling figures should, of course, be noted, finally, on the underside of the template, for this is the side that is uppermost when laid on the plate. If there is a wood deck, the positions of the centres of the various planks are noted on the template (in two cross lines, one at either end of the template), by means of a breadth batten supplied from the loft, the inner end of which is held to the centre-line nicks on the beams, as indicated in Fig. 16.

The beam holes and those in the end of the adjoining plate having been marked on the template, it is laid upon the plate, with its marked surface uppermost, and, if practicable, it should be so disposed as to avoid the necessity of shearing both edges and ends. The holes are now transferred with a marker (Fig. 6, Plate 91), and the various edge marks noted, either by setting off the spilings or by driving a fine centre punch through the marks

on the template, and when the centre lines of the deck planks are struck in with chalk, the template may be removed. If the outer edge of the plate is curved, it may be drawn on the plate with a flexible batten, or struck in with a chalk line, in short lengths. When, as is usual, the sheer strake is an outer one, the edge of the stringer plate should be sheared slightly beyond the surface of the frames as marked on the template, otherwise it must be sheared rather within them; and if the sheer-strake joints are butted, with continuous inside straps, the edge of the stringer plate must be cut back in way of them. The beam rivet holes, those transferred from the end of the plate already in place, and the holes for the wood-deck bolts, may now be punched, the latter in cross lines about 6 inches from either side of the beams—in many cases it is preferred to drill these holes in place (Art. 342). After this the plate is turned over to mark the edge holes, for in their case the upper surface is the faying one. If there is a gutter waterway, a third row of holes is required for the waterway bar (Fig. 16, Plate 89). All these holes are spaced by measurement, at a pitch of $4\frac{1}{2}$ diameters, for which purpose fore-and-aft lines are struck on the plate to represent their sides. The plan is, of course, consulted to ascertain what other holes are required; if, say, the bulkhead of a deck house connects to it above or below, the line of holes for the connecting angle must be struck in at the correct place, and the holes marked and punched from the proper side, above or below, according as the angle is above or below. Usually the only holes to be countersunk are those for the beams and in the overlapping end of the plate, but, of course, in way of doubling plates, none should be countersunk.

In the case of a **lower-deck stringer plate**, notches are required at each frame (Fig. 15, Plate 89), and in order that they may be properly outlined on the plate, the position and form of each frame must be noted on the template. This may be done by roughly shaping the ends of the cross bars of the template, discrepancies in fit being taken account of by spilings. The position of the intermediate frames, where there is no beam, and, therefore, no cross bar on the template, may be noted by means of a small detached mould, M (Fig. 15). When the template is in place, this is adjusted to each frame, as shown, and the outline of its inner end, being pencilled on the template, permits of its being replaced exactly as before when marking the plate. The holes for the shell lugs and gunwale angle should, of course, be punched from the upper side of the plate.

The foregoing description of the procedure of making deck stringer plates will serve also for ordinary deck plates, as also for those of the tank top. One point, however, should be noticed, and that is the method of arranging the corners of the plates at the lap joints. The ordinary method is to fit tapered liners as shown in Fig. 10, Plate 89. When the plates are very thin, liners are sometimes dispensed with, the corners of the plates being heated and thinned down on the anvil, as shown in Figs. 8 and 9. The heating and hammering of the corners is apt to cause a permanent buckling of the plate, and, accordingly, to avoid this, and the trouble of heating them, they are sometimes hammered cold, but the taper then impressed is usually very imperfect. It is now common to joggle the deck plating, and in such case it is well to discontinue the joggle in way of the deck angles of coamings, houses, etc., so as to avoid the clumsy tapered liners shown in Fig. 23, Plate 15.

Art. 518. Immediately the stringer plates are screwed up in place, the **gunwale bar** may be fitted. It is important that the upper-deck gunwale bar should be fair longitudinally, otherwise the sheer strake, the most conspicuous part of the hull, would be unfair. To ensure fairness,

the batten template employed to transfer the stringer-plate holes should have a fair outer edge and be fitted in long lengths, and, before marking the holes, be carefully faired by a skilful shipwright or loftsman. When the sheer strake is an outer one and has no doubling, the edge of the batten should project beyond the flanges of the frames by the thickness of the strake below the sheer, so that the frame liners behind the latter need not be tapered. The upper ends of the frames, however, are often unfair with one another (due to careless bending, or to their being pulled or pushed out of line by the riveting of the beam knees), and, accordingly, in fairing the batten it must be adjusted in such a way that, while fair to the eye, it may conform with the greatest number of frames. When the sheer strake is doubled below the stringer (Plate 104), care must be taken that the edge of the batten projects beyond every frame by not less than the thickness of the doubling. Forward and aft, where the side of the ship is sharply curved, an ordinary batten template would not bend sufficiently, and here, therefore, a special template must be made, composed of short pieces cut to shape and tacked together.

The following is the procedure of making the different lengths of gunwale bar. First the toes are planed for caulking, either by the plate planing machine or the special machine shown in Fig. 18, Plate 115; but, of course, if the horizontal flange is covered by a wood deck, it need neither be planed nor caulked. In work that is not high class, the toes of the bar are neither planed nor chipped before caulking. The next operation is to bevel the bar; the required bevel may be obtained from the ship or scrive board; amidships, where the side tumbles home, it is slightly close, but towards the ends it gradually opens. An open bevel, when very slight, may be neglected, otherwise it may be impressed cold in the beam-bending machine, as described in Art. 535; when considerable, the bar must be heated. In the case of the close-bevelled 'midship bars, it is very important that the bevel shall not be less than required, otherwise it is unlikely that the sheer strake will take contact with the heel of the bar; this defect is not uncommon, for the punching of the bar after it is bevelled tends to open the flanges. After the bevelling, the bar is bent to the required fore-and-aft curvature; when this is small, precision is unnecessary, for, so long as the bar is free from local irregularities, it is sufficiently flexible to pull into place. It may be bent in the beam-bending machine, the required curvature being ascertained by stretching a line from end to end of the place the bar will occupy in the ship, and noting the departure at one or two points from the straight. Those bars which are sharply bent must be heated, for though they might be bent cold in the beam bender, the operation would destroy the bevel; in such, of course, the bevelling is done hot, as described for frames. When bevelled and bent, the holes are transferred from the batten template, whose outer edge must, of course, be kept everywhere flush with the heel of the bar. The holes in the vertical flange may be punched advantageously before the bending. Those in the deck flange, if the curvature is considerable, should not be punched until after the bending, for the contraction of the flange during this operation would spoil their coincidence with those in the stringer. When bevelled cold, as described in Art. 535, no holes can be punched till afterwards, for their weakening effect would exaggerate the tendency of the flanges to curl over from heel to toe. To punch a small close-bevelled bar is not easy, for when the flange about to be punched is lying horizontally on the die, the holes may fall too near the toe (Fig. 11, Plate 89). To avoid this, the bolster is usually bevelled, as shown in Fig. 12. The rivet holes are generally countersunk in both

flanges, but when the deck is not sheathed, or when there is a gutter waterway, the points of the rivets in the horizontal flange may be of hammered type, and the heads of those in the vertical flange of ordinary pan type; when the gutterway is cemented, the projecting heads and points are advantageous in holding the cement in place. Care must be taken not to countersink the holes at the ends of the bars which take bosom pieces, and those which take rivets through the inner straps of the sheer-strake joints; mistakes are often made in this matter.

The continuous gunwale bar in the 'tween decks is made in a similar way to that just described for the upper-deck bar. The holes in the stringer plate are transferred by a template in the usual way, and care should be taken, when marking the holes on the latter, that its edge is kept in contact with each reverse frame. The holes in the latter, amidships, may be transferred by canting the template up on edge without shifting it longitudinally; very commonly these holes (if punched when making the frame) fall too near the toe or heel of the bar, due to the beams being raised or lowered when fairing them, and for this reason it is better to bear them after the beams are faired. The fit of the gunwale bar against the reverse frames is often very imperfect, particularly towards the bow and stern; this may be due to careless fitting of the gunwale bar, inaccurate bevelling of the reverse bars, unfairness in the frames, and variations in their depth—when of built type. Discrepancies are usually corrected by fitting washers behind the gunwale bar, or by locally distorting its flange with hammer blows, as shown in Figs. 8 to 10, Plate 80. The shell lugs may be fitted either before or after the shell, as described in Art. 512.

CHAPTER XXXVII

Art. 519. When the frames are faired, the **shell landings** may be **"sheered" or "lined in."** Their positions are already indicated by a nick on each frame, made on the scrive board, but these do not always give fair lines, for they are developed from the excessively fore-shortened line on the scrive board, they are roughly transferred, and the frames do not always occupy the precise position they were expected to do. As the landings are conspicuous, it is, of course, very desirable that they shall be fair; they are lined in by long *sheering battens*, which are fixed to the frames by clips, as shown in Fig. 22, Plate 92, and so adjusted that, while fair to the eye, they may coincide with the greatest number of nicks. Besides securing fair landings, the sheering operation is useful in that the breadths of the various strakes may be modified if required to suit the breadths of the plates ordered from the steel works, for when ordering these there is always a chance that, in the endeavour to minimize scrap, the ordered breadths may be rather less than what is actually required. Accordingly, as each strake is lined in with the sheering battens, its breadth is checked with the ordered breadths of the plates, and if these should be found to be rather scant, the battens are suitably adjusted to provide a sufficient margin.

The sheering operation is undertaken by a loftsman or skilful shipwright.[1] For his guidance he is provided with a list, giving the ordered breadths of each shell plate, the breadths of the landings, and the positions of the various end joints. The sheering battens are of pitch pine, about 40 or 50 feet long, by 3 by $\frac{3}{8}$ inch. They are applied to each landing separately, the ends of the different battens being overlapped. The forward and after bodies are taken separately. The first landing dealt with is that of the garboard strake, and then the others, consecutively, out to the bilge; after which the sheer-strake landing is taken, then those below, consecutively. Having placed the sheering battens to the nicks on the frames representing the garboard landing, and faired them to the eye, the breadths of the garboard strake so lined off are compared with the ordered breadths of the plates, by means of a flexible measuring batten, which is held to the frame and—if there is a bar keel—bent down the keel as the garboard plates will be bent. The breadths of each plate are, of course, given at its ends, and the necessary measurements are, therefore, made at the nearest frame. If the position of the sheering batten is found to be compatible with about 1 inch of spare material, its edge may be marked on each frame. As a rule it is more convenient to set off the ordered breadths of the plates on the frames before fixing the battens. The particular edge of the landing to which the batten is adjusted is usually the *sight edge*, *i.e.* the one representing the edge of the overlapping or outer strake; the other edge may not be a continuous line, for the breadth of the landing may diminish towards the bow and stern, according as the thickness of the plates and the

[1] A properly qualified shipwright should have passed through a period of training in the mould loft.

diameters of the rivets may vary. The amended landing edges being marked across the frames, they are nicked in on their toes, in such a way that, when the template is in place, they may be visible from the inside of the ship (Fig. 23, Plate 92); and the landing may be painted white, the shell flanges of the frames being sometimes coated with red lead before the sheering operation. The next operation is the sheering of the corresponding landing on the other side of the ship, and this is a simple affair, for, to ensure both sides being alike, the breadths of the strake just sheered are transferred by a short batten and pencil. In a full-lined vessel, the bottom landings for a large portion of the length amidships are straight, and these, therefore, may be struck in expeditiously with a chalk line.

Having sheered the garboard landings, the others are dealt with in a similar way, taking care to check the breadths of each strake with the ordered breadths of the plates. As a rule it is sought to increase slightly the breadths of the bottom strakes, so that while allowing a margin of breadth of about $\frac{1}{2}$ inch, there may be less chance of deficiencies in the breadths of the remaining ones at the bilge, where, owing to the transverse curvature, a considerable margin of breadth is always desirable. Having sheered in the lower strakes, those on the side are dealt with in a similar way, starting from the sheer strake. Where the landings terminate at the stem and stern post, care should be taken so to adjust the sheering battens that the sight edges of the plates shall fall between the rivets of these parts. If the vessel has a bilge keel, or fender, it also must be sheered in on the frames, so that the platers may know exactly where to punch the lines of holes in the plates.

After the various **landings** are marked on the frames, a **rivet hole** must be beared in each one, these particular holes having been omitted when punching the frames because of the uncertainty of the precise position of the landings. Only one hole is required (unless the plating or frames be joggled), which, of course, is placed next the sight, or caulking edge, a full diameter clear of it (see Fig. 23, Plate 92). In way of watertight bulkheads, two holes are required in the caulked frame angle, so as to maintain the watertight pitch of the frame rivets (Fig. 8, Plate 91). It often happens that the distance between the landing rivet and one of those next it is excessive, in which case an intermediate hole should be beared, as at R, Fig. 8. When the shell plating is joggled, the breadth of the landing from the sight edge to the remote part of the joggle, *i.e.* the distance AB, Fig. 26, Plate 92, is much greater than the breadth of an ordinary landing. Here, therefore, it is usual to make two holes in the landing; for if not, then, in the endeavour to minimize the distance between the rivets A and B, the latter frequently falls *on* the joggle (as shown in Fig. 25), which, of course, is very objectionable. Lloyd's rules now require two holes in the landings of joggled shell plating, and for a similar reason they also require two holes when the frames are joggled. When the landings are treble riveted the middle hole at each frame is omitted.

If the upper edges of the **sheer strake and bulwark** are parallel to the deck, then a note of this distance is all the information that the plater requires for the cutting of the upper edges of the plates. Very commonly, however, they rise upwards towards the bow, in which case upright battens are fixed to the gunwale bar, one at each butt of the sheer strake, and others between, say 6 feet apart, and sheering battens are then fixed to these, to represent the upper edge of the sheer strake and bulwark (and the main rail in sailing-ships), and when faired in the usual way, their edges and that of the gunwale bar are pencilled across the uprights, which are

then numbered and put aside for the subsequent guidance of the plater in preparing the sheer-strake and bulwark plates.

Art. 520. Immediately the shell landings are sheered in, the **fitting of the shell plating** may be proceeded with. This is usually contracted for by a squad of some six or seven platers, who divide the work among themselves into separate departments, so that each man, by acquiring special proficiency in his own work, may do it easily, quickly, and well. The work may be divided as follows: templating the plates; punching and shearing them; rolling, mangling, and countersinking; furnacing and shaping those of awkward form; fitting the finished plates on the ship. Two platers usually undertake the templating work, each assisted by a couple of boys; two also engage in punching and shearing, each assisted by a number of helpers (the precise number depending on the weight of the plates dealt with and the facilities for handling them), and other three take the remaining work, each assisted, as before, by helpers.

The necessary information is provided on an **expansion plan of the shell** and, in some yards, by a model of the ship. Although every detail is shown on the expansion plan, a model is useful in showing at a glance the shape and disposition of the various plates. Part of an expansion plan for a large vessel is shown in Plate 90. The following are the principal matters usually indicated. The ordered dimensions and marks of each plate (this, however, is often more conveniently provided in tabular form, in a small book, known as a "strake book"). The position, form, and thickness of all doubling plates, and the sizes and positions of cargo ports, sidelights, and scuppers. All watertight bulkheads, tank margins and divisions; the decks, intercostal stringers, keelsons, bilge keels and fenders. The breadths of the landings, lapped joints and buttstraps, and the size and spacing of the rivets. The different classes of riveting, whether double or treble, etc., may be shown conveniently by tinting the joints with different shades of colour, and providing marginal references; otherwise the riveting of each joint, whether single, double, treble, or quadruple, may be conveniently indicated by the letters S, D, T, or Q, or by marking across them one, two, three, or four short lines, as shown in Fig. 21, Plate 92. When both sides of the ship are not alike, indications must be given as to which side the particular marks apply. Large-scale sketches should be provided to illustrate the method of fitting special parts, such as the disposition of the buttstraps, the rivets in the sheer-strake joints, and tack rivets in the doublings; the mountings of cargo ports, etc. It is important that every feature affecting the fitting of the shell plating should be clearly shown, so that no trouble and expense may be incurred subsequently in drilling and cutting by hand after the plates are fitted.

In a vessel having a bar keel, the garboard plates should be the first dealt with, so that the frames may be rigidly united to the keel; for until they are in place the connection is the very imperfect one afforded by bent plate-washers (Fig. 9, Plate 96). The next strake fitted should be an inner one near the bilge, so that shores may be placed below it to support the increasing weight of the hull. Subsequently the remaining inner strakes of the bottom and side may be taken in hand, no particular order being observed. Corresponding plates on either side of the ship are fitted consecutively, for then the same template serves (without modification in its shape) for marking both; and in making the second, the plater has the advantage of familiarity with any special features peculiar to it. It is advantageous to template the plates consecutively, in a forward direction, for as the after end of each plate overlaps the one already in place, the end holes may be transferred from the template, like all the others, to the inside

of the plate, and all templated holes may be punched from this, the faying surface. When the joints are butted it is also advantageous to template the plates consecutively, for then only one end of each need be accurately fitted, and, if necessary, to secure a close butt, a small fore-and-aft adjustment may sometimes be made without appreciably affecting the fairness of the various rivet holes. The procedure generally adopted, therefore, is to template several plates of the inner strakes amidships, and while these are preparing, several at the after end, and, as the plates are put in place, to template the contiguous ones, working forward.

The general system of **templating** is described in Art. 491. A template, fixed in place for marking **a shell plate** of an inside strake, is shown in Fig. 8, Plate 91. When taken down it is turned upside down and laid on the inner surface of the plate, as shown in Fig. 3, and the holes and other marks are transferred. The plate, on the removal of the template, is shown in Fig. 2, additional holes being marked off to take the shell lugs of the deck stringer. The holes are then punched and the edges sheared, all from this, the inside of the plate; when this is done the plate is turned over, and the rivet holes in the landings, and forward, underlapping end, spaced off by measurement, as shown in Fig. 1. The breadth of the landings and the size and number of rivets between each frame are given on the expansion plan. To mark the holes, lines are struck in with a chalk line to represent the two rows of holes, and the rivets are then indicated by cross chalk marks, as shown. When a row of holes is indicated (for punching purposes) by a line, this is not struck through the centres of the proposed holes, but touching them; because the side of the punch forms a better guide than its centre, which can only be guessed at; and it is placed on that side of the holes which is the outermost at the punching machine, because, when a plate is in process of punching, it is then always in sight. The cross lines of rivet holes in the end joints are placed in line with the holes in the landings; when the latter are at their usual pitch, the width of the overlap is greater than is necessary (Fig. 27, Plate 92). When reduced to the normal (Fig. 28), two additional landing rivets may be required in this frame space. The holes in the joint are spaced by measurement ($3\frac{1}{2}$ diameters apart, or 4 if the joint is quadruple riveted), and if a deck, intercostal stringer, or keelson falls upon this particular strake, holes must be punched in line with its shell angle (Fig. 1, Plate 91). As the edges of an inside strake are out of sight, no great precision need be observed in shearing them; and if those of the rough plate are fair and neatly cut, and if there is only about $\frac{1}{2}$ inch of spare breadth, it is common not to shear anything off, but simply to increase the breadth of each landing by $\frac{1}{4}$ inch. As only the after end of the plate is caulked, it only need be planed. The ends of the shell plates are cut parallel to the frames, but, near the stern, where the landings may cross the latter very obliquely, they are often cut square to the landings, which has the effect of reducing the length of the joints, the number of rivets, and the length of the plates.

When a portion of two adjacent inner strakes is in place, and well bolted, the intermediate outer strake may be taken in hand, but, in the first place, its sight edges must be lined in, fair to the eye, on the inner strakes, as shown in Fig. 8, Plate 91. Their precise position is seen from the nicks made for the purpose on the toes of the frames during the shearing operation; if they are curved, the marks are transferred to the inner strakes at each frame, so that they may be struck in by a chalk line in short lengths. A second line, known as a gauge or "detective line," is sometimes struck in, 2 inches beyond the first, and is dabbed in at intervals with a centre

punch (Fig. 8). The edges of the plates are planed, and if the work is carefully done, they should, of course, when the plates are in place, be perfectly fair; if, through careless fitting, they are not fair, then the nature and amount of the discrepancy may at once be ascertained by gauging from the detective line; and if, to secure fairness, hand chipping is resorted to, the cost of the work may very properly be charged to the platers.

In Fig. 8, Plate 91, part of a template is shown in place for templating a plate of an outer strake; all the holes excepting those of the forward, under-lapping end are transferred by template, and all holes—with the same exceptions—are punched from the inside of the plate. The edges, as lined off on the inner strake, are usually transferred to the template by thickening the line with soft chalk, at intervals (as at B, Fig. 8), and striking the template against the marks with a hammer, but, of course, if the template does not cover the lines, spilings are taken. The edges of the plate are sheared about $\frac{1}{8}$ inch clear of the line, the remainder being planed off, and detective centre-punch dabs are made as described in Art. 491. If the edge is slightly curved, it is planed in short lengths, the man in charge of the machine adjusting the tool throughout the cut; when sharply curved it is chipped by hand, usually after the plate is fitted, as a prelude to the caulking.

After a shell plate is punched and sheared, its edges are planed and the holes countersunk; then, if it is curved, it is bent in the rolls (Art. 522), but if flat, it is passed through the mangle, unless, of course, it is already perfectly flat (Art. 537). Sometimes all plates are mangled with a view to flattening the rag existing around the uncountersunk holes. If the corners of lapped joints are tapered as described in Art. 312, the tapering is done after the punching and planing. If the landings are joggled, the plates are passed through the joggling machine as a final operation. When rolling transversely a plate having joggled edges, the joggled part, when it passes on to one of the lower rolls, is apt to cause an irregularity in the transverse curvature of the plate, about a foot or so from the edge, so that, when fitted in place, it may be difficult to bring the plate into close contact with the frames at this point. The method of templating joggled plates does not differ from that just described, for the joggling does not appreciably alter the breadth of the plate. The planing of the edges and machining of the corners is the only work not done by the platers themselves.

When the end joints are butted, great care is required in templating and cutting the end which abuts on a plate already in place; and if both of the contiguous plates in the same strake are in place, special care is necessary, for if the plate be cut a shade too long it may be impossible to fit it in place, and if too short a small endwise adjustment, while closing one butt, opens the other. In templating the ends, the method usually adopted is to make two or three tongue pieces overlap the end of the plate already in place, as shown at C, Fig. 8, Plate 91, and mark the latter across them with a fine pencil, the marks of which may be transferred to the plate by a chalk-line. In the case of an inside strake, the buttstrap extends over the landing, but as a rule the treble riveting of the butt is not carried on to the landing, the buttstrap being cut away where necessary to clear the landing rivets (Fig. 29, Plate 92), which may be placed rather closer together in this particular frame space. In the case of an outside strake, the butts of the plates should fall midway between the landing rivets of the inner ones, and if there is an odd number of rivets between the frames, an additional pair should be introduced, so that the butt may fall in the centre of the clear frame space, otherwise there might not be room between the frames to fit a treble-riveted strap.

Art. 521. The **garboard plates** are usually flanged first, then templated, cut, and punched; one end of each plate, however, should be planed before flanging. They may be **flanged either hot or cold**, as described in Arts. 536, 538, and 539, and illustrated in Fig. 4, Plate 83, and Figs. 1 and 12, Plate 95. The midship plates are all flanged to the same angle, which is ascertained by bending a small set (Fig. 7, Plate 92) at the ship or on the scrive board; in the case of those towards the bow and stern the angle becomes less acute and the frame portion may become curved; here a set is required for each end of each plate (Fig. 2). When the frame portion has transverse curvature, or "frame set," as it is termed (Fig. 3), it may be impressed in the hot-flanging machine at the same time as the flanging; if flanged cold, it may be impressed in the bending rolls before the flanging. During the cooling of a hot-flanged plate, the more rapid chilling of the edge of the flange causes the plate to warp, as shown in Fig. 4, and to allow for this, a slight reverse bend may be given to the plate while still hot, after flanging, by lifting one end and dropping it on a skid, so that the middle part may sag downwards. The plates are usually flanged in wholesale fashion; if hot flanged they are laid on top of one another, so that by cooling slowly they may have less tendency to warp. In the days of iron, the garboard plates were ordered of a specially good quality of iron, for ordinary plates could not stand the flanging treatment. When steel plates are to be flanged cold, the fact is (or should be) stated in the order to the steel works, so that a particularly mild material may be supplied and special ductility tests made (Art. 552). If the steel is not sufficiently mild, the plates, if sharply knuckled, are very apt to crack, especially if thick; very commonly a crack shows only for a few inches at either end, in which case it is sometimes remedied by welding, but, of course, in high-class work there should be no welds in any of the shell plates.

In the case of the **terminal garboard plates** at the bow, the frame portion is curved both transversely and longitudinally, and the flange is curved to suit the rounded fore-foot. If the curvature is slight they may be shaped as follows, and as illustrated in Figs. 5 and 6, Plate 92. First the line of the knuckle is chalked on the plate, and the keel edge sheared approximately to shape; then the plate is put in the bending rolls, and a short piece of angle bar, say, 2 feet long, inserted below the top roll and over part of the knuckle line; the roll is then depressed so as to bend the plate, as shown in Fig. 6, and the same operation being repeated from end to end of the plate results, gradually, in a longitudinally curved knuckle. If a hydraulic press, such as that described in Art. 542 (Fig. 10, Plate 115), is available, the same effect may be produced by it, rapidly and conveniently. The flange so formed is not a flat surface, and the remainder of the plate has yet to be curved; to complete the work, the plate is heated and laid with its flange on the slabs (the remainder being supported so as to stand up at the proper angle), which is then beaten down flat (Fig. 5, Plate 92). The remainder is then hammered over until the upper edge bears against a stout set bar, bent previously to the required fore-and-aft curve of the landing (as ascertained by bending a light set-iron at the ship), and fixed at the proper height on the slabs, so as to form a sort of *bed*. In the case of plates which are sharply curved, a proper bed must be made as described in Art. 525.

After the **garboard plates** are flanged they are **templated** in the following manner. Two templates are employed (Fig. 7, Plate 92), one for the keel and one for the frame portion of the plate; the former should be about $\frac{1}{2}$ inch narrower than the depth of the keel, and both should be

neatly made, with straight edges, of the same length, and long enough to take the frame beyond one or both ends of the plate. When fixed in place at the ship to mark the holes, the upper edge of the keel template is placed flush with the top of the keel, and the frame template is adjusted with its lower edge just touching the other, as shown in Fig. 7. In order that the two templates, when applied to the plate, may be placed in their proper relative positions (not those they now occupy), two sets, bent to conform with the ends of the plate, are placed in position against their forward and after ends, and when so placed, the lower edge of the keel template and the upper edge of the other are chalked upon them (Fig. 7). A pencil mark is also made across the meeting edges of the two templates, to permit of their being placed in the same relative fore-and-aft positions when applied to the plate. Having marked the holes in the keel and frames, the templates may be removed. The sets are now placed each one against its particular end of the plate, and the positions of the top and bottom edges of the templates, as chalked thereon, transferred to the plate, as shown in Fig. 8. The templates are then applied to the plate, as shown in Fig. 8, with their edges coincident with the marks just made upon it, their precise relative fore-and-aft positions being secured by the mark made across the meeting edges. It will be found that, as now placed, the edges of the two templates do not touch as they did at the ship, due to the fact that each one has been moved laterally, away from the other, by its own thickness; if they occupied exactly the same positions, the holes transferred from them would be unfair, more or less according as the thickness of the templates were great or small. When applying the keel template to the flange, care must be taken that its upper edge is parallel with, or in the same plane as, the frame portion of the plate, for the flange may have bent longitudinally, in its own plane, during the cooling. The keel rivet holes, as marked on the template, should not be transferred to the plate by a centre-punch, as is often done, for it is then very difficult to secure concentricity when marking and punching them. The ends are sheared and planed as described for margin plates (Art. 515), and as this is awkward work, one end of each plate should be planed before flanging, and the templates should be so applied that only the other end need be cut, this being the one fitted against the plate already in place.

In some cases the **garboard plates** are **punched and cut before flanging.** This method has the advantage that the plates may be more easily manipulated at the punch, shears, and plane, but, on the other hand, great care is necessary in the flanging work, so that the knuckle may be in its proper place, and also in the templating, so that both the keel and frame rivet holes may be coincident. If flanged hot, the smaller contraction of the flange (due to the chilling effect of contact with the metal of the flanging machine) is often sufficient to throw out the keel rivet holes and spoil the closeness of fit at the butts. The templating may be done as follows. As before, two detached templates are employed, the one for the keel portion is placed with its upper edge flush with the top of the keel, but the other with its lower edge distant from the keel by the difference between the two distances ABC and ADC in Fig. 9, Plate 92, the former being measured on the neutral axis of the garboard plate, and the latter on the keel and frame. The two templates, having been marked, are laid on the plate with their edges *touching*, and when the holes, etc., are transferred, the plate is punched, cut, and flanged, the greatest care being observed that the position of the knuckle and its radius are those assumed in the templating.

The correct assignment of the distance between the two templates is the principal feature of this method of working. It may be determined simply and accurately by bending an experimental strip of plate, of the same thickness as the garboard plates, with the same radius of knuckle as it is proposed to bend them. Before bending it, two centre-punch dabs are made on its surface (the inner one as regards the ship), say 10 inches apart, one on either side of the region of the knuckle. And after bending it, it is adjusted in place at the ship, and the position of the dabs marked upon the keel and frame; the distance between these two marks is then ascertained by measuring up the keel and out on the frame, and the excess over 10 inches, whatever it be, is the distance required between the edges of the two templates, or, in other words, the extent to which they must be brought together when marking the plate. The first plate should be tried in place immediately it is made, to test the accuracy of the method of working. Sometimes the templates are connected by hinge-like strips of tin (Fig. 10, Plate 92), in which case, when fixing them in place, the strips must be made to assume the proposed radius of knuckle of the garboard plate; and they should lie in the position of the centre of the thickness, or neutral axis of the garboard plate at the knuckle, otherwise a correction must be made for the extension or contraction which occurs with the flanging. The buttstraps of the garboard plates are bent to fit the knuckle, and they should be tapered so as to pass well down between it and the keel (Fig. 11).

Art. 522. Shell plates may be divided into **six classes**: those which are flat; those which are curved in a transverse direction only, as those on the bilge amidships (Fig. 16, Plate 92); those which are curved only longitudinally (Fig. 17); those which have both transverse and longitudinal curvature, with or without twist (Figs. 18 and 19); those which are sharply bent both transversely and longitudinally, such as the boss and oxter plates (Fig. 20, Plate 92, and Fig. 7, Plate 93); and those which are flanged, such as the garboard plates (Fig. 1, Plate 92).

As the **bilge plates** amidships have the same transverse curvature, or "frame set," from end to end, they are cylindrical, and may be readily bent to any radius in the rolls. When templating those of an outer strake, the template must be adjusted everywhere at the same distance from the frames, a condition conveniently secured by clamping to the latter, midway between the two inner strakes, a fore-and-aft batten of the proper thickness (Fig. 12, Plate 92). If the central part of the template took contact with the frames, the plate also would take contact with them when fitted in place with the edge holes coincident, and, consequently, tapered liners might be required.

The bending of a bilge, or other curved plate, causes the inner surface to contract and the outer one to stretch, with the result that the breadth of the plate, and the spacing of the frame rivet holes, diminishes on the inner surface and increases on the outer. This effect is shown in exaggerated form in Figs. 5 and 6, Plate 93, which represent the same two plates when flat and when bent; it will be observed that, while the spacing of the holes in both plates has diminished on the inner surface and increased on the outer, it has not changed on the neutral axis, halfway between the surfaces; and the outer plate in Fig. 6 is, therefore, still 1 inch broader than the inner one, when measured on the dotted lines. The amount of contraction and extension depends on the thickness of the plate and how much it is bent; if a plate is bent right round to form a tube, the breadth of its inner surface, now the inner circumference of the tube, will be smaller than that of the outer by 6·28 times the thickness of the plate

(the circumference of a circle being 6·28 times the radius). But as the outer surface stretches during the bending as much as the inner one contracts, the actual stretch and contraction is only half of this, or 3·14 times the thickness; if bent to a quarter circle, it would only be one-quarter as much, or, roughly, three-quarters of the thickness; if to one-sixth of a circle, one-sixth as much, or half the thickness.

Whether or not, in templating a bilge plate, a correction should be made for the contraction of the inner or faying surface, and the consequent drawing together, transversely, of the various rivet holes, depends on the thickness of the template and how it is placed with regard to the frames. If it is the same thickness as the plate, and is placed in the same position, against or clear of the frames, no correction is required, for its inner surface will contract with the bending (and stretch when straightened) just as much as that of the plate. If it were only half as thick, and its inner surface were still placed in the position of the inner surface of the plate, then, as the contraction of its inner surface would only be half that of the plate, half the allowance given above would have to be made. If, for instance, a plate were bent to a quarter of a circle, the edge rows of holes and the edges of the plate itself, as transferred to its inner surface from the template (assumed to have a thickness half that of the plate), would require to be spaced three-eighths of the thickness of the plate further apart, and the spacing of the frame rivet holes (in the region of the bending) proportionately increased. If a perfectly thin template were used, say one of sheet tin, then, of course, the full allowance of three-quarters the thickness of the plate would be required. The necessity for making any allowance may be avoided by so adjusting the template that the centre of its thickness (whatever this may be) is distant from the frames by half the thickness of the plate. Thus, in the case of the sheet-iron template shown in Fig. 14, Plate 92, although its inner surface does not contract (when bent as shown) like that of the plate, still, the frame holes, as marked upon it for transference to the plate, would, by reason of the remoteness of the template from the frames, be further apart to begin with, by an amount exactly equal to the contraction of the plate. Through neglect of the foregoing principle, it is common to find a very imperfect coincidence in the rivet holes of the bilge strakes, especially when the plates are broad and the bilge sharp.

The bilge plates, when punched, sheared, countersunk, and planed, are bent in the rolls. The required curvature is ascertained by bending a small set-iron to the frames, and care should be taken to bend the plates properly, *right out to the edge* (Art. 536), so as to avoid tapered frame liners, an open seam, and imperfect caulking. A very exaggerated case of defective work of this kind is illustrated in Fig. 13, Plate 92.

Art. 523. In many curved plates the **transverse curvature varies from end to end**; if the variation is small, it can be impressed in the bending rolls, by depressing one end of the top roll more than the other, but if it is considerable it cannot, for, properly speaking, cylindrical rolls can only roll cylindrical plates, whereas a plate having a variable curvature is conical (plate bending rolls are described in Art. 536). In an extreme case, for instance, if one end of a plate—in process of rolling—is flat, and the other much curved, say to the radius of the top roller, then, while the flat end must, in order to remain flat, move horizontally through the rolls, the other, to remain curved, must revolve with the top roll without any lateral movement, and it is evident that the two different motions are impossible in the same plate, for if one end revolved so would the other. In the actual work of rolling a plate, when the variation in its curvature from end to end exceeds a certain moderate limit, the pressure and

friction arising from the antagonistic movements of different portions becomes so great as to stop, or jam, the rolls; in which case the top roll must be elevated and the plate withdrawn, or the rolling may be continued if the plate is adjusted, by pulling the flat end slightly outwards so as to place the curved part more nearly parallel to the axis of the rolls. As described in Art. 536, a local excess of curvature may be produced by rolling in with the plate sheet-iron or thin slabs of wood, which, of course, has the effect of locally increasing the diameter of the rolls, making them conical or barrel-shaped instead of cylindrical. It does not help matters to heat the plate, for while its greater pliability would avoid the jamming of the rolls, its lesser elasticity would cause it to alter form as it emerged from the rolls, *i.e.* its curved part would flatten and its flat part become curved, an effect which occurs more or less even with cold plates.

Nearly all **curved shell plates** have more or less "**twist.**" A plate is twisted when its four corners are not all in the same plane (Fig. 18, Plate 92). If a plate is passed crossways through the rolls it will have transverse curvatures only; if passed endwise, longitudinal curvature only; but if in any diagonal direction between these, it will have both transverse and longitudinal curvature, and twist, the degree of twist depending on the amount of curvature and the direction of rolling. In the majority of shell plates there is some general direction in which all parallel lines are nearly straight, and such plates may usually be formed with sufficient accuracy in the bending rolls, for, of course, in all rolled plates, lines drawn parallel to the axis of the rolls are straight. When the transverse and longitudinal curvature is such that in no direction can straight lines be drawn, the plate cannot be rolled to its precise form, either its transverse or longitudinal curvature, or its twist must be sacrificed to some extent. Now, it is not essential that a plate, when ready for fitting, should have the precise curvature required, for, if approximately correct, the bolts will pull it into place, close against the frames. In preparing a curved plate, therefore, what is aimed at is to secure accuracy in its transverse curvature, for, as regards longitudinal curvature and twist, its flexibility is usually such that the bolts may pull it home against the frames. If, however, the plate is very broad, and has considerable transverse curvature, the pulling of it into position lengthwise is very apt to produce a kink in the edge, as shown in Fig. 19.

In the actual work of making these plates, the plater takes account of the transverse curvature by bending a light set-iron to a frame at either end and one or two intermediately. He also takes account of the longitudinal curvature and twist; often a mere scrutiny of the form of the ship at this part suffices, otherwise the deflection from the straight may be noted by stretching a line from end to end, and the twist by suspending a plumb line from each top corner, and measuring the distance from them to the lower corners, the difference in the two measurements indicating the twist; or if the plate has a hollow outer surface, the twist may be ascertained by stretching two lines diagonally from corner to corner, and noting how far out the end of one must be moved in order that it may touch the other where they cross. The most suitable direction in which to roll the plate, so as to combine in the greatest degree correctness of curvature and twist, may be ascertained by noting in which direction lines stretched along the berth are the straightest; a skilful plater can usually judge of these matters by a mere scrutiny of the berth. During the subsequent rolling of the plate, the transverse curvature is checked by applying the frame sets, and if necessary the direction of rolling is altered to suit different parts of the plate, and the curvature may be increased

locally by inserting sheet iron or thin slabs of wood between the plate and the rolls.

A plate which has slight **transverse and longitudinal curvature,** without twist, may be formed by first rolling it transversely with an excess of curvature, and then longitudinally; the latter operation, while producing longitudinal, causes a loss of transverse, curvature, but when this is in excess in the first instance, it may finally be what is required; the elasticity of the steel prevents the entire loss of transverse curvature, even when the longitudinal is so great as to involve considerable rolling pressure, and if necessary it may be more fully maintained by placing a slab of elm wood in the middle of the plate and perhaps one under either edge, and rolling them in with the plate, as shown in Fig. 15, Plate 92. If the transverse and longitudinal curvature is considerable, both cannot be impressed in the rolls, and in such cases the necessary form is secured by heating the plate after the transverse rolling to a dull red, and laying it with its ends upon blocks, so that its unsupported middle part may sag downwards by its own weight, assisted, if necessary, by hammer blows; it must not be heated very hot, or it will lose transverse curvature, and become otherwise misshapen.

Art. 524. The **stem plates** (and those connecting to the stern post) are usually templated and punched before they are knuckled or flanged; and, as a result of careless work, the stem holes are often bad, which circumstance, owing to their large size, is most prejudicial to the efficiency of the riveting. The stem portion of the template is usually united to the remainder by strips of tin, and in applying it in place to mark the holes, the strips should be made to lie exactly as the knuckle of the plate itself will lie, and in the centre of its thickness, otherwise the holes will not correspond after the knuckling. And in knuckling the plate, care must be taken to place the knuckle in its proper position and give it the radius assumed when marking the template; often it is too far forward or aft, and it may not be parallel with the stem, defects which are a common source of bad holes. In order that the plates of the outer strakes may fay close upon the stem, the inner ones are tapered (usually by hand chipping) in way of the landing, as shown in Figs. 1 and 10, Plate 93. In many cases, to reduce the tapering work, it is done as shown in Figs. 2 and 11; and sometimes, to avoid it altogether, tapered liners are fitted, as shown in Fig. 3, but this is very clumsy.

Art. 525. The **oxter plates** are those which take the sternpost, immediately below, or partly on, the transom; one of them is shown in Fig. 7, Plate 93. Owing to the sharp bend, variable transverse and longitudinal curvature, and twist, they are usually undevelopable, *i.e.* they cannot be made from a flat plate (and, conversely, be flattened out) without stretching or compressing the material at places, and they must, therefore, be moulded to shape when softened by heat. The same remark applies to the boss plates and a few others. In such "furnaced plates" it is obvious that the holes must be punched and the edges cut after they are shaped, for before this it is uncertain at what precise places the various bends and configurations will fall. To mould an oxter or boss plate to shape may require several heats, and to provide, therefore, for the loss of thickness by oxidation and local stretching, they should be ordered rather thicker than is ultimately required.

In shaping a **furnaced plate** much preliminary work is required. The first operation is to make a **skeleton mould** at the ship. This is done by bending $\frac{3}{8}$-inch round-iron bars to the curve of each frame, and one to the fore-and-aft curve of each landing, welding them roughly

together, and trying the completed mould in place to correct its curvature (Fig. 8, Plate 93). Sometimes flat bars are employed instead of round, say 2 inches by ¼ inch, which are punched and riveted together. Very commonly only an outline mould is prepared, the set-bars for the intermediate frames being kept detached for independent application to the plate in process of making, the twist being ascertained as just described. Some workmen prefer to make their moulds of wood, cutting the different pieces—of stout material—to the shape of the frames and landings, and nailing them all rigidly together.

The next operation is to make a **bed**; this, as shown in Fig. 9, Plate 93, is simply a substantial and more or less accurate counterpart of the skeleton mould, whereon the hot plate may be laid and hammered to shape. It may be made in various ways, depending on the stock of bed material at disposal, the shape of the plate, and the practice of the workmen. As a rule only the more prominent features of the plate are represented, for when these are impressed, the remainder of the shaping work may be done when the plate is comparatively cold, independently of the bed, by judicious hammering and the repeated application of the skeleton mould or sets. In some cases the bed is simply an arrangement of bars and blocks, designed to support the hot plate at a suitable inclination, so that the part which requires manipulation may lie in a convenient position for hammering. As ordinarily made it is built up on the slabs, of iron bars (of any section) and strips of plate (wide or narrow), which are bent to the fore-and-aft or transverse shape of the plate, or across any prominent feature, where, owing to a sharp bend or reversal of the curvature, it is desirable to have a check on the form and something solid on which the hot plate may bear. The bars are fixed in position on the slabs in different ways; some may be bolted together, and their ends may be turned down and hooked in to the slab holes, or they may be fixed in position by upright bars or dogs, supporting blocks of wood or iron being introduced where necessary. Nicety of construction or even accuracy of shape is not aimed at, the principal requirement being a fair approximation to the shape of the more prominent features of the plate, and sufficient strength and rigidity to withstand the weight of the plate, the displacing effect due to its being dragged forcibly over upon it, and the subsequent hammering. Sometimes a bed is formed by making an excavation in the ground, to the shape of the skeleton mould, and lining it with bricks or cement, but this method is slow and inconvenient.

The plate, when at a soft yellow heat, is pulled out of the furnace by tongs, with chain attached, over upon the contiguous bed. It is very important that, from the moment it leaves the furnace, the utmost despatch should be used in getting it in its proper position on the bed, ready for hammering down, for it soon loses its heat, and while a few blows, or even the weight of the plate itself, may effect a wide alteration in form when at a yellow heat, very many and much effort are required to produce the same effect at a lower temperature. In order, therefore, to expedite the work, and at the same time reserve the energies of the men, a winch (preferably machine driven) should be employed for dragging the plate from the furnace on to the bed, and arrangements should be made to ensure its sliding automatically into its proper position upon it, by suitably inclined skids, guide bars, and stops. As soon as it is in place it is struck down, around its margin and elsewhere, by long-handled wooden mallets, for, in its soft state, hammers would indent it; as it cools and hardens, sledge hammers are substituted, but the blows should be struck not directly on the plate, but on a flattening iron, held by the plater in charge in the most

suitable position for producing the desired effect. The result of direct blows from heavy hammers is often observable in furnaced plates by an unsightly, lumpy appearance, and more particularly in the case of thin plates.

The great heat radiated by the plate is one of the principal difficulties in working it, for, as it is a painful matter to remain at close quarters, long-handled tools must be employed. The heat may be greatly minimized by placing corrugated sheet iron on those parts which are not in process of hammering; the greater part of the plate, for instance, may be covered during its passage from the furnace to the bed. The getting of the plate into position on the bed is the critical part of the operation, for it is then so hot as to be almost unapproachable, and should it catch on some part of the bed as it is pulled over it, or slip out of position, the necessary adjustment can only be made with difficulty, by pulling it with hooked bars and raising it with long levers, and, of course, the loss of time and consequent chilling of the plate may make it impossible to hammer it to anything like its proper shape, and may, therefore, necessitate a full second heat. Oxter plates and others which are sharply bent must be heated more than once; during the first heat they are moulded approximately to shape, and during the second sharp corners are finished off and the general form adjusted to correspond with the skeleton mould. At the second heat the plate is not raised to more than a dull red, for if hotter it would flatten of its own weight; and to prevent it from losing in the furnace the form already impressed, supports must be placed below those parts which curve upwards from the furnace floor; wooden blocks are generally used for this purpose, for, although they burn away, they may endure for the short period of the reheating. After the second heat, when the plate is cold, considerable manipulation may still be required to fair it and adjust its shape precisely to that of the skeleton mould. Even when quite cold a large modification in form may be produced by skilful hammering, but very commonly, especially with a thick plate, it is preferred, rather than work it quite cold, to warm it to a "black heat" in the furnace, for even at this low temperature the steel is much more amenable to bending treatment (Art. 561). In the case of an oxter plate, to finish off the sharp corner at the heel of the transom frame, it is usually necessary to heat this part in a smith's fire, but such local heating is objectionable in that it is apt, in the absence of annealing, to result in cracks of the kind described in Art. 562, which often do not occur until the riveting work is almost complete. When fitted in place on the ship, discrepancies in fit are usually corrected by heating the plate locally with the blast of a specially designed oil lamp, and simultaneously screwing up and hammering the plate. In many cases furnaced plates are first brought approximately to shape when cold, in the rolls or cold-flanging machine, after which they are heated (not too hot) and finished off on a bed as just described.

Furnaced shell plates, like all others, are in pairs, but as they are on different sides of the ship the configurations are all transposed, and, accordingly, a separate skeleton mould and bed must be made for each one; as a rule, however, the making of the second plate is a simple matter, for most of the sets may be worked in again, by simply reversing them. In different vessels of similar size the boss and oxter plates are often much alike, and for such plates, therefore, it is convenient to keep a stock of substantial pattern beds (in duplicate for port and starboard), which may serve, with little modification, for a large number of plates. They are made of plates and bars, bolted together with countersunk bolts, and so arranged that they may be taken apart and extended or adjusted by

superposing additional, or changing certain parts. Very commonly, in the case of the boss plates, a few cast-iron beds or thick pattern plates are kept in stock, by means of which the main features of many of them may be readily formed.

In the case of light-scantlinged vessels, whose shell plating is less than $\frac{1}{4}$ inch thick, a furnaced plate would lose its heat before it could be moulded to shape, and the hammer blows on the soft, thin steel would produce lumps. In such cases, therefore, the plates are shaped in a cold state, by long-continued hammering on an anvil or block having a rounded, flat, or hollow surface, such as is used by coppersmiths.

Art. 526. When an oxter or other **furnaced plate** is brought finally to the proper shape, its holes and edges are **marked for punching and cutting.** This may be done either by applying the plate itself in place, or by a template. If a template is employed, it is carefully made of thin wooden battens, bent to the frame surface in such a way that the whole fits close at every point; if there are sharp corners round which wood battens cannot be bent, strips of tin or lead are employed. After marking the holes and edges, the template—which retains much of its curved form—is applied to the plate, and if this has been properly shaped it should fit close at every part. Care must be taken to place it in the same position on the plate that it occupied at the ship, *i.e.* relatively to the same configurations, this being readily done by making corresponding marks on the template, and on a couple of set-irons bent to the ends of the plate, in the manner described for garboard plates. The holes on the template are marked on its convex or faying surface, and it is evident that their spacing on the other or concave surface (supposing them to be bored through) must be rather less, due to the radius of curvature of this surface being smaller than that of the other by the thickness of the material of the template; now, as it is the latter surface which is applied to the plate, it is the latter improper arrangement of holes that is transferred to it, which means, of course, that if so punched they would not correspond with those in the frames. This will be clear from Fig. 26, Plate 93, which represents, in section, part of an oxter plate with the template (in which the holes are shown as bored) laid upon it, also the frame from which the holes in the template were marked. The distances FF, TT, and PP are the same, but it will be observed that the holes in the plate have not been transferred from those in the template, for if they had, they would be so out of position as to be "half-blind" with those in the frame. The spacing, as transferred from the template, is increased by the sum of the two distances OP, OP, which, if the angle A were 90 degrees, or one-quarter of a circle, would be $\frac{6{\cdot}28}{4}$ times the thickness of the template; or, if one-sixth of a circle, $\frac{6{\cdot}28}{6}$ times the thickness, etc. If the template were perfectly thin, then, of course, no correction would be required.

It is evident, therefore, that to mark an irregularly curved plate by a template (unless it be made of thin sheet iron) is a difficult matter, for, owing to the variable curvature, the correction in the spacing of the holes as transferred from the template would vary throughout the plate; a skilful plater may approximate very closely to what is actually required, but as often as not the result, as regards fair holes, is far from satisfactory. For this reason it is always desirable that an irregular, furnaced plate should be marked, not by template, but by applying the plate itself in place, and in practice this is generally done, a hole being punched near the centre of gravity of the plate for a bolt attachment for the hoisting tackle.

The trying of it in place is, of course, very useful in checking its form. Many of the holes in an oxter, or dished keel plate, cannot be punched, in which case they are drilled, and those parts of the edges which cannot be sheared or planed are cut and chipped by hand. To avoid the labour of fitting a furnaced plate in place, and, after marking the holes, taking it down, drilling it and bringing it back, it is often preferred to drill the holes in place, and, to avoid having to do this from the interior of the ship, which may be inaccessible for such work, some of the holes in the furnaced plate may be punched, the corresponding ones in the parts to which it connects being left blank.

Art. 527. The **frame liners** are fitted immediately the outer strakes are in place (Figs. 9 and 11, Plate 11). As they are mere fillings they are made of a cheap brittle iron, known as "liner iron," or "packing;" sometimes it is so bad as to crumble when drawn out hot under the hammer, but, of course, such material should not be employed. Liners which are caulked, such as those in way of tank margins and divisions, gunwale bars, etc., should be of ordinary iron or steel. A large quantity of liner iron of various thicknesses and breadths is usually kept in stock, in bars 15 or 20 feet long; but sometimes it is ordered in short pieces, all of the proper length and thickness for the different strakes of plating throughout the hull; and it may also be tapered, as required, for clinker strakes.

The frame liners should fill the vacancies between the frames and shell with such accuracy that nowhere may a thin-bladed testing knife be inserted; often, in bad work, the rivet shanks may be felt with the knife, in which case these particular rivets, when subjected to stress, may readily loosen and admit water. Accordingly, as absolute and permanent water-tightness in the shell rivets is essential, special care should be taken in fitting the liners. Those which fall between inner strakes of different thickness should be tapered to suit; as a rule, however, when the difference is only $\frac{1}{20}$ or $\frac{2}{20}$ inch, they are made of the smaller or mean thickness. Of course, if tapering were dispensed with when the difference was considerable, the rivet at the end of the liner could not draw the three parts properly together (see Fig. 14, Plate 93). Very commonly, when parallel liners are employed, the effect of taper is secured by introducing a thin supplementary tapered liner at one end (Fig. 15), or even a slip of sheet iron, but such work is rough and does not usually stand the test of the knife. In high-class work each liner should be of such thickness and taper as to fit in its place without supplementary filling slips. The sheer-strake liners require special care, for the tops of the frames may be displaced by the fitting of the beams, and so are not always in a fair line with the heel of the gunwale bar.

The fitting of liners and similar unskilled work is usually undertaken by riveters, who, from age or infirmity, are unfit for heavy work. They are prepared with small templates. Those which are curved are bent either in the rolls or by hammering, a small flat-iron set being bent to the frame as a pattern. In high-class work the rivet holes should be punched no larger than those in the frames, and as the liner is a middle thickness, a small die should be used, so as to minimize taper. Very commonly this is disregarded, the holes being punched a size larger, so as to minimize the effect of non-coincidence and ensure the free entry of the shell rivets; but, of course, the soundness of the latter and their efficiency under stress is then greatly prejudiced. And, for a similar reason, it is evidently desirable that the liners should consist of one thickness, for the greater the number, the less the chance of fair, cylindrical holes. Frame liners are not put in

place until the shell plates are screwed up, so that they may be slipped in between them and the frames; but in way of intercostal stringers and decks, where they cannot be introduced in this way, they are fixed in place previously, either by tying them to the frames with spunyarn, or by driving wooden plugs through the holes; bolts cannot be used, of course, for they would interfere with the fitting of the plates. Bulkhead liners, being large and heavy, are secured in place by bolts having flat, disc-like heads, which may be forced through by a punch after the shell plating is fitted.

Tapered liners are drawn down under the steam hammer. When the taper is slight, only a foot or so of the end is tapered. With clinker strakes, the liners are tapered from end to end; but, excepting those for thick shell plating, they are usually made short, say, one-half or one-third the breadth of the strakes. Liners for thin deck and tank-top plating, in which the strakes are arranged clinker fashion, are usually made quite short (12 inches or so), this being advantageous in saving weight and avoiding some three-ply rivets. The ends of tank-top liners are cut an inch or so short, to provide air passages. The frames near the bow and stern are sometimes incorrectly bevelled, in which case special **knife-edged liners** may be required in way of the inner strakes, and transversely tapered ones in way of the outer (Fig. 18, Plate 93). To ensure sound rivets, such liners must be carefully made and fitted, and more particularly at the bow, where the shell riveting is severely tried by panting stresses and blows from the waves; of course, in high-class work they are never required. Frame liners of special form are often fitted behind the oxter and boss plates (Fig. 20), for, owing to the awkward form of these parts and the excessive bevelling and curvature of the frames, close contact throughout is rarely secured; in consequence of bad work at these places, leaky shell rivets are not uncommon.

Besides the frame liners, short tapered ones are required in way of every overlapped end joint, unless, of course, the corners of the plates are machined (Figs. 21 and 24, Plate 93). They are usually made sufficiently long to take three landing rivets, and as they are caulked they must be of good iron or steel. They are tapered in bulk under the steam hammer, and, to facilitate and expedite the work, two are usually made in one piece, by drawing out both ends of a flat bar, as shown in Fig. 19; they are then sheared to the proper breadth, and, after the caulking edge is planed, they are cut in two. Very commonly, instead of planing the edge, it is chipped in place as a prelude to the caulking, and, instead of chipping it flush with the edge of the shell plate, it is sometimes left projecting in the unsightly fashion shown in Fig. 24. They are either marked in place or by small templates, and care should be taken that the thin end is perfectly thin, and that the thick one butts close against the end of the shell plate. The work is often defective in these matters, the liner being so short, and the taper so imperfect as to cause sharp depressions and lumps in the shell plating (see Fig. 23); and the thick end may be cut short, or sheared so roughly as to preclude a close fit, in which case the resulting open conduit for water is merely plugged on the outside by driving in a wedge-shaped fragment of iron. Sometimes, when the end joints of contiguous strakes fall within 4 or 5 feet of one another, instead of fitting a tapered liner at each one, as shown in Fig. 21, a single parallel liner is introduced from joint to joint, as shown in Fig. 22. This improves the appearance of the shell plating, for it avoids the sharp bends or twists which occur in the sight edge at each tapered liner; it has the disadvantage, however, of involving numerous three-ply rivets and double caulking.

Besides the ordinary **frame liners**, supplementary thin liners are **introduced** at various places, not to fill vacancies, but **to secure fairness in the shell plating**; they are fitted, for instance, even when, by joggling the plating or frames, ordinary liners are dispensed with. Although the frames may be bent with the greatest care, their outer surface is never perfectly fair, *i.e.* individual frames, or groups of frames, may at places lie a little within or beyond the normal fair surface. The resulting waviness in the shell plating may or may not be conspicuous; as a rule it is only noticeable when the eye is cast along the prominent landing edges, for on the plane surfaces between these there is nothing for the eye to follow. Irregularities are most observable on straight fore-and-aft surfaces, especially on the flat of the bottom, because, when regarded from one end, the whole area may be focussed simultaneously, the fore-shortening effect giving prominence to irregularities, however small and unimportant; a curved surface, on the other hand, must be focussed more or less in detail, and, consequently, irregularities may escape notice. Unfairnesses occur chiefly on the bottom and bilge, because, while the fairing ribbands may pull the side frames into line, they cannot do so with those on the bottom, on account of the stiff floor plates; and, moreover, though the frame angles may be properly bent, the riveting of them to the floors may displace them slightly, and they may not all sit at the proper level, on the keel.

It is usual, in all shipyards, to correct any unfairnesses which are undesirably prominent, by introducing liners of suitable thickness at the "slack" frames, *i.e.* those which fall within the normal surface. As a rule, if the irregularity is small, it is only corrected in way of the landings, for, as just seen, it is hardly noticeable elsewhere. The necessary adjustment is usually made by the riveters, just before the riveting, as follows: In the first place, the landing connecting two strakes, and the two strakes themselves, are screwed up tightly for a distance of 20 to 40 feet, and, having chalked the sight edge in way of each frame, the eye is cast along so as to detect any unfairness; if there are hollows at places, the particular frames which, by their slackness, are the cause of them, are at once located by the chalk marks, their bolts are slacked off, and a workman within is notified to force the plate outwards, which he does by driving a wedge between it and the frames. When the landing is faired in this way from end to end, short, double-tapered liners are substituted for the wedges, as shown in Fig. 16, Plate 93, and the riveting work is then proceeded with. A stock of tapered liners is usually made in the smith's shop for the purpose, from 12 to 18 inches in length, and varying in thickness from $\frac{1}{8}$ to $\frac{1}{4}$ inch; if thinner are required, sheet iron is used, and if thicker, special ones are made. It is evident that the system of joggling the shell plating or frames, while dispensing with ordinary liners, does not avoid those fitted as above, for fairing purposes.

In some shipyards a **special procedure** is adopted, whereby perfect fairness of the shell plating is secured, not only in way of the landings, but throughout the breadth of each strake. By this system the ordinary frame liners are made of such thickness that they not only fill the vacancies between the frames and the outer strakes, but make good any discrepancies in the fairness, and liners are also introduced as required in way of the inner strakes, as shown in Fig. 17, Plate 93. The work is done as follows: When the landings are sheered in on the frames, and before the plating is wrought, a fine line is stretched tightly against the frame surface (20 or 30 feet at a time) in way of each landing, so as to discover those frames which are slack; and the distances between it and these particular frames are then noted in figures on each frame. Supposing, now, that a frame is

found to be $\frac{1}{2}$ inch slack at one landing, $\frac{3}{8}$ inch at the next, and $\frac{1}{4}$ inch at the next, then, to bring it fair, one of the two liners required would be $\frac{1}{2}$ inch thick at one end and tapered to $\frac{3}{8}$ inch, and the other $\frac{3}{8}$ inch thick and tapered to $\frac{1}{4}$ inch; if the latter falls in way of an inner strake, these figures represent its thickness and taper, but the other, being in way of an outer strake, must, if the inner strakes are, say, $\frac{1}{2}$ inch thick, be 1 inch thick at one end and $\frac{7}{8}$ inch at the other. In this way, the thicknesses of all the liners are noted, so that they may be prepared in the smith's shop, ready for fitting immediately the shell is in place. If absolute fairness is desired, some liners on the bottom frames may be of abnormal thickness, sometimes as much as $1\frac{1}{2}$ inch in way of the outer strakes. To detect unfairness in curved surfaces, a flexible batten is substituted for the line.

Although the above method of fitting liners results in a perfectly fair shell, it has, apart from its costliness, the very considerable disadvantage of increasing the number and length of the three-ply rivets, and of adding to the weight of the hull; and it is, therefore, questionable if the quality of perfect fairness is not dearly bought, in view of the fact that, so long as the shell is free from marked local irregularities, unfairnesses have no real prejudicial effect on the structure. There are many, however, who regard perfect fairness in the shell as a criterion of excellence in the workmanship generally.

CHAPTER XXXVIII.

Art. 528. The **building of masts, yards, etc.,** requires exceptional skill, and, consequently, it is not every plater who can turn out satisfactory work. The draughtsman who designs the spars makes an elevation, section, and expansion plan of each one. The expansion (which need only be for one strake, all strakes being alike) shows the breadths of the various plates, and is obtained by measuring the diameter of the spar at various points, multiplying by 3·14 to obtain the circumference, dividing by two or three according as there are two or three strakes, and adding the breadth of the landing. For the guidance of the plater the breadths of the finished plates so obtained are marked on the plan, but as the fairness of the spar is dependent on the accuracy of these measurements, it is usual to check them by making a full-size expansion of one strake, as shown in Fig. 12, Plate 93. This is conveniently done on the mould loft floor, but usually the plater does it himself, for which purpose he lays out the plates, end to end, so that they may serve as a sort of drawing board, on which he sets off the breadths and draws in the outline with a long batten. According to some procedures the plates are laid out in this way for marking purposes, but in the procedure about to be described each plate is marked separately, and quite independently of those adjoining. Most spars have a rounded or barrel taper, and it follows that the edges of the strakes and of individual plates are also rounded, but as the amount of curvature in each plate (most plates are not usually longer than 10 feet) does not usually exceed about $\frac{1}{8}$ inch, it is generally neglected, which simplifies the work and does not appreciably affect the fairness of the spar. Having noted (from the full-size expansion) the precise breadth at each end of each plate, the various plates may be marked forthwith for cutting and punching, in the manner described below.

Consider the procedure of **preparing the plates** of the yard shown in Fig. 13, Plate 93, composed of two strakes with overlapped end joints. The three middle joints are butted, with inside straps, to permit of the sling hoops being slipped over them. One strake is here an outer one, and if it were necessary that the longitudinal seams should fall symmetrically with a diameter, it would require to be broader than the other, for it has a larger radius; in practice, however, to simplify the work, all strakes are made of the same breadth. Proceeding to mark one of the plates, its breadth at either end is first set off. Now, from the expansion just made, only one breadth was obtained at each joint, and it is evident from Figs. 5 and 6 that the same breadth cannot be used for the ends of both plates, for as one overlaps the other it has a larger radius and must be broader. If the breadths obtained from the expansion are taken to represent those of the overlapping ends, those for the underlapping ends must be reduced. As the circumference of a full circle is 6·28 times its radius, any increase or reduction made in the latter is accompanied by 6·28 times as great an increase or reduction in the former. In the case illustrated in Fig. 6, which represents a section through an overlapped

joint, the radius of the inner plate is $\frac{5}{16}$ inch smaller than that of the outer one (measuring to the neutral axis in either case), and consequently its breadth, or girth, is $\frac{5}{16}$ inch by $\frac{6{\cdot}28}{2}$, or practically 1 inch smaller. In Fig. 5 the same plates are shown flattened out, and the difference in breadth is here apparent; the breadths of the plates, when bent as in Fig. 6, are the same as when they are straight, if in the former case they are measured on the neutral axis of the plates.

Proceeding with the marking of the plates: The breadth at either end (one of which is amended as just described) having been set off, the two edges and the centre line are struck in with chalk (as a rule, of course, only one side need be sheared), after which one end is marked square to the latter line, with a tee square, as shown in Fig. 25, Plate 93. The next operation is to mark the edge holes; this is done with a pattern template (rather longer than the plate and the breadth of the landing) in which rivet holes are accurately bored 5 diameters apart, as shown. Its ends are cut 1 diameter clear of the terminal holes, and when adjusted to the edge of the plate, one end is placed coincident with the end of the plate as just marked. Having marked the holes in both edges, the other end of the plate is struck in, 1 diameter beyond a rivet in either edge, the plates being ordered with a sufficient margin of length. The edges of all plates are marked in this way, and it is evident that as the spacing of the holes is identical and continuous throughout the length of the spar, all holes must coincide when the two strakes are put together.

The next operation is the marking of the holes in the ends of the plate for the lapped joints. The three rows, for treble riveting, are placed in line with three of the edge holes just marked (this is convenient but not essential), and cross lines are now struck in, touching the sides of the latter, as shown in Fig. 25, Plate 93. The pitch of the rivets is here, as in the seams, 5 diameters, and a pattern template, having holes accurately bored at this pitch, may be conveniently employed for marking them. Now, it is evident that if the holes are spaced 5 diameters apart in, say, the overlapping end of each plate, they must be spaced closer together in the underlapping end. In any particular case the necessary modification is obtained by dividing the difference in the breadths of the two plates[1] by the number of spaces between the holes across the joint. Thus, in the case illustrated in Figs. 5 and 6, the difference in the breadths of the two plates is 1 inch, and this divided by 8, the number of spaces, gives $\frac{1}{8}$ inch; *i.e.* the rivet pitch in the inner plate must be $\frac{1}{8}$ inch less than that in the outer. The modification must, of course, be made in such a way as not to disturb the symmetry of the holes about the centre line. To avoid the necessity of making frequent computations and accurate measurements, a stock of pattern templates may be kept, suitable for plates of different thickness and for spars having two and three strakes. The same principle must, of course, be observed when marking doubling plates and buttstraps.

All plates having been marked in the foregoing manner, they are cut, punched, and countersunk. It is common to punch all plates from the inside, for, when a small die is employed and the plates are thin, this does not appreciably affect the efficiency of the riveting. The edges of the outer plates must be sheared from the outside, so as to secure close seams, and for this purpose the lines are reversed—by nicking the ends of the plates in way of them. As masts, etc., are not usually caulked, the edges

[1] The difference is 6·28 times the thickness, divided by 2 or 3, according as there are two or three strakes; if the plates are of different thickness, their average thicknesses should be taken.

of the plates need not be planed, except, of course, at the end joints if these are butted and connected by inside straps.

The next operation is the **rolling of the plates.** For this purpose a section at each end of each one is drawn with a pair of large compasses on a board (the diameter of the spar being given on the plan at each joint), and when any particular plate is about to be rolled, a couple of light set-irons are bent to the shape of its ends as so drawn.

Small bending rolls are employed for spar making. In design they are practically the same as ordinary plate-bending rolls, except that the top roll is raised or lowered by hand gear, and the upper part of the standard carrying one end is made portable, to permit of tube-like plates being withdrawn from it endwise. Few machines are capable of dealing with plates longer than 10 feet, for if the top roll—which must be of small diameter—were longer than this, it would bend too readily. This roll is of forged steel, and its diameter does not usually exceed 10 inches, but a smaller one may be kept for special work.

The plates are always bent hot, for the pressure required to bend them cold would be so great as to cause the small top roll to spring, so that the ends would have a smaller radius than the middle. Care must be taken to roll them square to the centre line, for, if twisted, the edge holes would not correspond with those in the contiguous strake. With tapered plates this is accomplished by first passing them through parallel to one edge, and then back parallel to the other, a simple method, because a plate tends naturally to enter the rolls with its leading edge parallel to their axis. The curvature is tested from time to time by applying the set-irons, and it is carried out to the extreme edge by inserting a convex bar of iron, as shown in Fig. 9, Plate 95, and by subsequent hammering. Before the plates are quite cold their inner surface should be coated with redlead (Art. 468).

The bolting together of the various plates and the subsequent **riveting** are operations requiring considerable care, for if carelessly done the completed spar may be crooked. Whatever the size of the spar, it is screwed up complete by the plater to check the accuracy of his work; and if angle stiffeners are required they are now fitted, by applying a long template to the outside and marking it by striking it over each hole (punched for the purpose in each plate) with a hammer, or if the spar is sufficiently large, a boy may mark the holes from within. When the diameter is as large as 18 inches, it may be riveted when screwed up complete, the holder-up working within, with a long-shafted hammer used lever fashion (Fig. 19, Plate 47), and in such cases large holes (about $1\frac{1}{2}$ inch diameter) are usually provided at intervals (or a plate may be left off, or loose, here and there), through which the hot rivets may be passed to a boy within, who inserts them in the holes over the holding-up hammer. Small spars must be put together and riveted plate by plate, the holding-up work being done from the outside, and the spar growing gradually in length. During the riveting of a spar it is rolled over as required, so that the joint in process of riveting may be on the top; and care must be taken to keep it quite straight during the riveting, otherwise it will not be so when finished.

Art. 529. The form of the outer surface of the hull is not that of any well-known geometrical solid; amidships it is cylindrical, but forward and aft it becomes complex, partaking of the character of a paraboloid. The **stern plating**, however (above the *knuckle line* and abaft the transom, Fig. 4, Plate 94), is an exception, in that it is practically always cylindrical in form, being formed by the rolling of a cylinder in a curved path. A cylinder in process of rolling out the stern is depicted in Fig. 4. The

reason for assigning this form to the stern is that the plating is then developable, *i.e.* it may be flattened out, or expanded; consequently, it is readily **laid off in the mould loft**, and its actual construction is simplified; further, the method admits, as required, of considerable variation in the appearance of the stern. The ordinary transverse frames, being parallel to one another, may all have their true form scrived down on the boards. The **stern frames**, however, being disposed radially, cannot be so treated; in their case, therefore, their true form is supplied to the workmen by means of outline moulds, made in the loft. And similarly in the case of the stern plating, its expansion in the loft permits of template moulds being made to the form of each plate, so that these may be cut, punched, and rolled, ready for erection at the same time as the stern frames.

As the work of **expanding the stern** is of constant recurrence in the shipyard, it will now be described.

A drawing of the stern, with all the necessary geometrical construction lines for laying off and expansion, is given in Fig. 3, Plate 94. As already observed, the stern plating lies all above the knuckle line; the surface of the hull below is not cylindrical, but is arbitrarily formed with the rest of the hull, and is plated in the usual way. If the stern is designed with an upper knuckle, as shown in Fig. 4, Plate 33, the strip of plating above the latter is not usually expanded, but is templated in the ship after the stern frames are erected. The form of the stern plating is fixed by two lines, the straight rake line SS′, Fig. 3, Plate 94, and the curved knuckle line K′K′; these being drawn as required, the stern may be laid off. It will be observed, from Fig. 4, that the cylinder, in rolling out the stern, remains parallel to the centre line and to itself, its curved path being determined by the knuckle line; and it follows that each line of contact of the cylinder with the plating is parallel to its axis and is a buttock line. Suppose, now, that only the rake line SS′ and knuckle line K′K′ are drawn in plan and elevation (Fig. 3). The rail line RR must now be drawn in elevation to suit the taste of the designer, and then projected into the plan by means of the buttock lines B_1, B_2, B_3, etc. The points of intersection of the latter with the knuckle line in plan are, for this purpose, projected up to the knuckle line in elevation, and as the buttock lines in elevation must all be parallel to the rake line SS, or axis of the cylinder, they may at once be run up to the rail line as shown. This being done, the rail line may be drawn in plan, by projecting its points of intersection with the buttock lines just drawn, down on to the same lines in plan.

The stern frames may now be drawn in plan (Fig. 3, Plate 94). The actual construction of these frames is shown in Figs. 2 and 4, Plate 33, and described in Art. 250, and they may be considered as extending from the transom frame right round the stern to the transom beam. Their spacing having been marked off around the knuckle line in plan, they are drawn in as straight lines from the transom to the rail line (as shown in Fig. 3, Plate 94), so as most uniformly to divide and stiffen the stern plating. The vertical flange of the stern frames is kept plumb, so that it appears as one line in plan. Having drawn the frames in plan, they may be projected into the elevation, by squaring up the points of intersection with the rail and knuckle line. The points in elevation, where they cut the transom frame and beam, are ascertained from the actual form of the latter parts, which, in the case of the transom frame, is shown in Fig. 3; and as the portion of the stern frames on the counter may be curved in elevation, a transverse section abaft the transom should be drawn on the body plan, and the frame heights, where they intersect this, lifted and transferred to the stern expansion now in process of laying off.

Where the stern frames do not lie parallel to the buttock lines in plan, they must be curved in elevation between the knuckle and rail line; this follows from the fact that when a plane cuts a cylinder (or cylindrical surface) in a direction not parallel to its axis, the line of intersection, or trace, is always curved. To obtain the correct curve of the stern frames at this part, a point in each one between the rail and knuckle line must be found. For this purpose a water line (WW, Fig. 3, Plate 94) is drawn in elevation, midway between the rail and knuckle line, and, having projected it into the plan, its points of intersection with the frames here may be projected into elevation, and thus give the required third point in the curved line of each frame. As a rule the curvature in most of the frames is so slight as to be negligible. The transom frame below the knuckle has already been laid off with, and to suit, the adjoining surface of the hull, and its shape above the knuckle must now be obtained (for the body plan) agreeably with the cylindrical formation of the stern as just designed. Its form is readily obtained by simply measuring, in plan, its breadth at the rail, knuckle line, and intermediate water-line, the heights of these points being obtained from the elevation (see Fig. 3).

The stern being laid off, as just described, may now be expanded. To do this it must be cut by an imaginary plane at right angles to the rake line or path of the cylinder. The trace of this plane (*i.e.* its line of intersection with the stern plating) is a straight line in elevation. Draw any straight line, therefore, say, XX, Fig. 3, Plate 94. Its true form (X″X″ in plan) must now be obtained, by swinging it down into the horizontal, this operation being shown by the arcs in elevation drawn with point S′ as centre, and its intersection with each buttock as radius. The points thus revolved into the horizontal may now be projected on to their respective buttock lines in plan, and the curve X″X″, representing the true shape of the line XX, drawn through them as shown. Imagine now that the rake line SS′ is revolved backwards into the horizontal position S^2S', and that XX is (together with the whole of the stern plating) revolved with it into the vertical. In its new position XX will appear as the straight line X′X′ in plan. Though it appears to be straight, it is, of course, curved, and only touches the paper at the centre line; and what is now required is to flatten it out, or expand it (and with it the stern plating) into the horizontal, or plane of the paper. Its true form is shown by the curve X″X″ in plan, and it is, therefore, possible to measure round it, and take its girth with a flexible batten, ticking off on the latter the points of intersection with the various buttock lines. The batten is then laid out straight along the line X′X′, and the various marks transferred to the latter. These points are the expanded positions of the buttock lines, *i.e.* the positions they occupy when the stern plating is flattened out, and lines b_1, b_2, b_3, etc., may now be drawn through them; these, the new buttock lines, are, of course (from the principle of the cylinder), still parallel to the centre line. To obtain, now, the outline of the expanded plating, the rail and knuckle line must be drawn upon it. This is done by measuring in elevation the distance of the rail and knuckle line on each buttock from the line XX, and setting them off on the corresponding expanded buttock lines in plan (from the expanded line X′X′) and running curves through the points so obtained. The shape of the expanded stern plating, as now drawn, is shown in outline in Fig. 3, and for clearness it is also shown separately in Fig. 5.

It is now required to draw on the expanded stern plating the lines of the stern frames and transom, so that when the plates are cut to shape the necessary rivet holes may be punched for their connection. To do this the rail and knuckle lines in plan (Fig. 3, Plate 94) are girthed with a flexible

batten, and the positions of the stern frames and transom noted upon it; the batten is then laid along the expanded rail and knuckle lines, and the points, being transferred, lines drawn between them from rail to knuckle line will represent the stern frames and transom. Some of these lines may be slightly curved on the expansion, and to obtain the proper curvature their points of intersection with the mid-way water-line should be girthed as just done for the rail and knuckle line, the water-line being also drawn for the purpose on the expansion (not shown in Fig. 3). To obtain the positions of the stern frames on the expansion with absolute accuracy, water-lines only must be used, instead of the rail and knuckle lines; because, owing to the sheer of the latter, their girth in plan is not precisely their true girth.

Having now obtained the expanded, or flattened, form of the stern plating, with the positions upon it of the stern frames, the butts of the various plates may be marked off and templates made for each plate, the rivet holes being bored in the butts, if lapped, so that each plate may be cut and punched, ready for erection, independently of its neighbour. In most cases, however, only one large skeleton mould is made, from which the plates may be laid off in position on the scrive board in the manner described for bulkheads. The joints of the plates are disposed vertically between the stern frames, and, to save workmanship, the plates should be large. The lines, curved or otherwise, of the stern frames are transferred to the plates from the template, the holes being transferred from the stern frames themselves, after these are made. The holes in the upper and lower edges, at the rail and knuckle, are spaced by measurement. The rolling of the plates is a simple matter, for, owing to the cylindrical form of the stern, they are all rolled in one direction, *i.e.* parallel to the buttock lines, which, for this purpose, are indicated on the templates; and the exact curvature of each plate is supplied to the workmen by a mould or sets made or bent to the true form of the line XX (Fig. 3, Plate 94) in way of each plate. The lower edge of the stern plating is usually flanged or knuckled, and this is done after the plates are rolled to shape, at a smith's fire; and to prevent the plates changing shape with the heating and hammering, it is well to bolt to them a short angle bar, bent to the required curve, with its heel at the line of the knuckle, so that it may form a stiff corner for the flanging action.

The shape and bevel of the stern frames are supplied to the workmen by moulds made in the loft, one for each frame. The necessary laying-off work is shown in Fig. 3, Plate 94. The outlines of the frames, as shown in elevation, are not their true outlines, excepting those frames which in plan are parallel to the centre line. To obtain the true form of, say, frame No. 3, it must be revolved, in plan, parallel to the centre-line. The points E, F, and G, of the rail, water-line, and knuckle thus obtained are then projected into the elevation, and as the frame is swung in a horizontal plane they are, of course, still in the same horizontal lines in elevation. A line E′F′G′ drawn through these points gives the true form of the frame in way of the stern plating. The part lying between the knuckle line and the transom may be curved, and if correctly laid off in the elevation, its true shape may be readily obtained by means of an additional transverse fairing section abaft the transom. To obtain the bevels of the frame, its toe and heel must both be drawn in elevation (as shown in Fig. 3), when the bevel at any point may at once be lifted, as shown in Fig. 3, and as described in Art. 481. Having obtained, by means of the round of beam line of the transom beam, the height of the forward end of the radial stern beam, an outline mould, with the bevels marked upon it, may be made for

each frame, from which they may be bent to shape, bevelled, and fitted with beam and floor bracket, ready for erection in the ship. The holes in the vertical lugs of the floor bracket and beam, and in the transom floor and beam, may be marked by pattern templates, so that the stern frames, when erected, may be bolted in place at once, ready to receive the stern plating, also made by this time and ready for erection. No ribbands need thus be used. The holes in the stern plating, as already noticed, are transferred from the frames, either by templates or by applying the frames themselves to the plates as the latter lie on the ground.

Art. 529A. Formerly, a vessel's stern (and bow, when of clipper type) was usually ornamented with **wood-carving**; as this, however, was found to result in corrosion of the plating below, through imprisoned moisture, and was costly, the practice was gradually discontinued. An exception is often made, however, of the knuckle moulding, for an iron moulding is awkward to fit, owing to the curvature and bevel. The wood is usually bolted on in the rough, and shaped in place. At one time fore-and-aft, **half-round iron mouldings** were always fitted at the upper edge of the sheer strake and rail, now they are often dispensed with; when fitted they are either of hollow section, as shown in Fig. 9, Plate 74, or of flat, convex section, as shown in Figs. 6 or 7. **Hollow moulding** is advantageous, in that it is lighter and cheaper than solid. It is inferior structurally, however, because, as the connecting rivets are not entirely surrounded by metal between their head and point (Fig. 10), their soundness and efficiency under stress is necessarily imperfect; and as water is free to enter the moulding and flow fore and aft, it may pass through the plating by any rivet head which may be imperfectly laid up, or through joints covered by the moulding, the caulking of which may, perhaps, have been rendered imperfect by the riveting of the moulding. For this reason the classification societies do not sanction the use of hollow moulding on the side of the ship below the deck, or where leakage might do harm. When a moulding is fitted in line with a gunwale bar, bulwark landing, or rail, it is usually only connected by every third or fourth rivet.

CHAPTER XXXIX.

Art. 530. The number and variety of the **machine tools** employed in different shipyards vary greatly. Small establishments may possess only those that are essential (some of which may be of very antiquated type), namely: plate-bending rolls, an edge-planing machine, two or three punching and plate-shearing machines, an angle-shearing machine, a beam-bender and horizontal punch, a garboard-flanging machine, countersinking and drilling spindles, a circular saw, and steam hammer. High-class yards are equipped with modern machine tools of all kinds, in number sufficient to carry on, without delay, all the work in the busiest times. A number of representative modern machines is shown in Plate 115, and a description is also given of each one. The arrangement or disposition of the machines relatively to the building slips and to one another is an important matter in facilitating the work, *i.e.* in minimizing the labour of transporting and handling the material. It varies in different yards according to the space at disposal; in some it is excellent, in others it is quite the reverse; nevertheless, it is of interest to note that the operations in the latter may proceed apparently with no less expedition and economy than in the former, due to the circumstance that the workmen stationed in any particular yard become accustomed to the prevailing arrangements and to the machine tools at their disposal. The greater number of the machines are usually placed under a long, open shed, near the tops of the building slips; a few, however, such as angle shears and beam benders, are usually placed in a more or less isolated position, where an unrestricted space around them is required for the manipulation of the long bars with which they particularly deal.

The machines may be driven either by belt gearing (from a shaft, fixed to the roof of the shed and driven by a large steam or gas engine), or each one separately by a small attached engine. Both methods have their advantages and disadvantages; the former is simpler and more economical in some respects, but it restricts the positions of the machines. Small electric motors are now extensively adopted for driving purposes, one being affixed to each machine, and driving it direct, or by a short belt (see Figs. 1, 2, 4, and 5, Plate 115); this method is perfect in every way, and, as a couple of wires takes the place of the wasteful steam piping or cumbrous shafting, the machines may be placed in whatever positions are most convenient. Practically all large shipyards are now equipped with certain hydraulic machine tools, namely: a large manhole punch, a cold-flanging machine, hydraulic riveters and bears. In some yards the hydraulic installation is extensive, the numerous cranes and derricks alongside of the building slips, as well as those affixed to the machine tools, having hydraulic lifting appliances.

Art. 531. Punching and shearing machines are very commonly designed each one to perform the two operations of shearing and punching, and in many cases a third mechanism is added, for shearing angle bars,

or punching limber holes, small manholes, or stringer notches. Machines of this three-function type are shown in Figs. 3 and 12, Plate 115; and Fig. 5 shows one designed to do four operations. It is evidently convenient to be able to shear and punch a plate at the same machine, while suspended from the one crane; nevertheless, as the punching of a plate takes seven or eight times as long as the shearing of its edges, punching machines are more continuously in requisition, and, consequently, in yards having a large number of machines, a considerable number are usually designed for punching only. In order that a punching machine may punch holes in the middle of a broad plate, the depth of its *gap* or *gullet* must be at least half the breadth of the plate; modern machines have often a gap 42 inches deep, but a 30-inch one is usually sufficient, taking, as it does, plates 5 feet broad. As a deep gap increases the leverage or disruptive effect of the punch, it involves a heavy, costly machine. In the case of shears, a comparatively shallow gap suffices, for, however broad the plate, it is only its edge or marginal part that is shorn; if it should be required to cut a long plate in two, a line of contiguous holes is punched across it. Modern punching and shearing machines are usually built with sufficient strength to deal with plates at least $1\frac{1}{4}$ inches thick, for although material so thick is rarely used, and might, therefore, be provided for by one special machine of large power, still, a large margin of strength in all machines is very desirable as a provision against the rash action of careless workmen. In yards which undertake the construction of warships, machines of special power are required to deal with the thick protective plating; some of these are capable of shearing 2-inch plates and of punching 2-inch holes in 2-inch plates. Some punching machines are designed to punch two holes at each stroke; these are useful when punching the two rows of holes required in double-riveted seams (such as the shell landings, etc.), a hole in each row being punched simultaneously; and, as the punches may be used separately and be of different sizes, a useful choice may be offered to the workmen. For girder work, or work where there are numerous parts having rivet holes at a fixed pitch, multiple punching machines are employed; some of these are capable of punching a line of twenty holes, more or less, simultaneously.

There are two distinct types of punching and shearing machines, the "*eccentric*" (Fig. 3, Plate 115) and the "*lever*" (Fig. 4). The latter has an advantage over the former in that the punch may move with varying speed throughout its stroke. In ordinary piecework punching operations, the machine is driven at the highest speed compatible with a sufficiently long interval between the strokes to shift the plate, so that the mark of the hole next to be punched may be adjusted precisely under the descending tool. Now, in order that, with a quick-working punch, there may be a maximum of time to adjust the plate, it is evident that that portion of the interval between strokes, when the punch is actually in contact with the plate, should be short, and the remainder long; that is to say, the punch should move quickly at the lower part of its oscillation, so that it may have the more time to spend clear of the plate. With a lever machine this result is readily secured, for the cam which actuates the lever, or "*rocking beam*," may be so shaped as to cause the latter to move rapidly at one period of its stroke, and slowly, or with a pause, during the remainder. In an eccentric machine an eccentric disc takes the place of the cam, and as it is circular it can only produce the well-known invariable harmonic movement. The lever design has the further advantage that the small transverse dimension of the part of the machine over the punch permits of the workman who guides the plate getting close to the work. As regards

shearing machines, a stroke of varying speed is not advantageous, and consequently the lever design is most usefully applied to punches; when applied to shears, the cam is usually a mere disc, the resulting movement being, therefore, the same as that of an eccentric machine. Punches are always provided with a stop motion, so that by pushing a bar or lever, or turning a hand-wheel, the punch is instantly disconnected; plate shears do not require a stop motion, angle shears do, although in some old-fashioned machines it is not provided.

A useful **application of the plate shears** is shown in Fig. 19, Plate 95, wherein one of the flanges near the end of a Z bar may be removed (about 1 inch at each stroke); this may be useful when it is required to crop the end of the bar, for, with one flange removed, the remainder, being of angle section, may be cut in the ordinary angle shears. And Fig. 18 shows a method of removing the bulb from one side of a bulb bar, Fig. 13, Plate 81, showing how the same work is done by hand. Another useful application of a punching or shearing machine is shown in Fig. 1, Plate 80, wherein an open bevel may be readily impressed on a cold angle bar, the degree of bevel being varied by placing sheet iron below the heel. Punching and shearing machines may also be adapted for joggling plate landings, in the manner shown in Fig. 1A, Plate 95, the work, when so done, being perfect in every respect.

Art. 532. A combined angle-shearing, beam-bending, and horizontal punching machine is shown in Fig. 7, Plate 115, and part of an **angle-shearing machine** is shown in outline in Fig. 20, Plate 95. It will be observed that there are two knives, a right and a left-hand one; both are necessary when it is required to crop the ends of a frame or other angle bar which is already bent to shape, for although one of the ends may be cut by the right-hand knife, the other can only be cut by the left, unless, of course, the curved bar is raised high above the ground, or the end to be cut is inserted from the back of the machine; but to cut from the back of the machine involves the distortion of the end of the bar, due to the crushing effect of the descending blade (Fig. 22, Plate 95). As angle bars are usually straight when cut, a single knife is in most cases sufficient, hence the utility of the single angle shears often introduced as a third movement in punching machines (Fig. 3, Plate 115).

Art. 533. Machines are now specially made **for cross cutting channel, Z, and bulb-tee bars.** All ordinary shearing machines, whether for plates or bars, distort the part removed, owing to the descending knife bending it down before it has entirely severed it (Fig. 22, Plate 95). This, of course, does not matter when the ends of a bar are merely cut to bring it to length, for the part removed is of no value; but when it is required to divide a bar into two or more pieces, the distortion of one end of each part is very objectionable; if there is length to spare, the damaged portion may be sheared off, but, if not, the end must be heated and dressed by the hammer. In the case of channel bars, etc., the distortion is very considerable, but as they are practically always ordered in separate lengths for each part, the circumstance is comparatively unimportant.

A **hydraulic machine**, specially designed **for cross cutting channel and other bars,** is shown in Fig. 15, Plate 115. It has a small hydraulic locking ram, R, which, by holding the bar firmly down, permits of its being cut precisely to the required line, whether square across or at an angle; and the whole machine may be revolved on a vertical pivot, so that long bars may be entered from any direction and cut at any angle, without slewing or adjustment. Fig. 11 shows another hydraulic

machine, having double lower knives, between which, as a die, the upper one descends, making a double cut and taking with it a thin slice of the bar; both the severed ends are thus left perfectly free from distortion. The lower knives are adjustable, to suit different sizes and kinds of bars. The fact that the ends of the bars are not distorted permits of their being inserted under the knife either from the front or the rear, an important matter in the case of Z frames, for it enables both ends to be cut after bending. A machine specially designed for beam work is shown in Fig. 14. Not only does it cross cut Z, channel, bulb-tee, and other bars, but combines in itself a horizontal punch and a beam bender. And it has the novel feature of a horizontal shears, specially adapted for removing the bulb or flange from one side of a bulb-tee or Z bar; this is particularly useful in beam-making operations, when, in the absence of this machine, these parts must be cut off by hand. In shipyards which have none of the above special appliances, channel bars, etc., may be cross cut by a cold saw (of circular or band type); this makes a neat cut, but is very slow in action. Or they may be heated in a smith's fire and be cut by chisel. When the part removed is of no value, it may be cut off in detail, as shown in Fig. 21, Plate 95; first one flange is removed, as described below, and what is left of the bar, being of angle section, may be cut in the angle shears.

With **channel or Z frames** it is sometimes necessary **to remove the inner flange** at the top or bottom end, so as to make them of simple angle section (Plate 108). This may be readily done by nicking the flange across with a cold chisel, as at A, Fig. 21, Plate 95, splitting the web longitudinally from the end of the bar to this point, punching conjoined holes between the end of the split and the nicked flange (if the former is not close to the latter), and then breaking the flange off with a sledge hammer. The web may be most conveniently split with the shears; for this purpose an ordinary knife cannot be used, for the stiff flange on the part removed would offer such resistance to its bending or depressing action as forcibly to cant the bar; a short curved knife is, therefore, substituted (Fig. 23), which, when at the bottom of its stroke, barely passes below the fixed one; and, to prevent canting of the bar, a block of iron is placed alongside of the lower knife, below the upper one and sufficiently low to clear it, when at the bottom of its stroke, by the thickness of the bar. Sometimes the upper knife is arranged to work in a die, *i.e.* between two lower knives; there is then no canting tendency, but, of course, a longitudinal strip of the web is removed. In some cases the web is split in the plate-edge planing machine, by making repeated cuts with a narrow tool, but this is slow and part of the web is removed. When it is required to split small channel or Z frames in way of the floor ends, so that one part may form the frame angle and the other the reverse bar, it may be inadmissible to remove any material from the web, lest the floor flanges of the two split portions be too narrow.

Art. 534. A useful tool, sometimes termed a "**ripping punch**," is shown in Fig. 24, Plate 95. It is a rectangular punch, about $1\frac{1}{2}$ inches long by $\frac{1}{2}$ inch thick, at one end of which there is a guide piece; the other portion works like an ordinary punch, making at each stroke a 1-inch slot. The guide piece does not leave the die or bolster; it serves, therefore, to guide the work, so that each rectangular slot may be a continuation of the one just punched; and the punch may be made to follow a straight line or a curve. It is well adapted for splitting channel or Z bars, and for cutting lightening holes in small plates; for the latter purpose it must, of course, start the cut in the centre of the plate, which may be accomplished by raising the punch bodily (by applying an external lifting force to the slide of the

machine) until the guide piece leaves the die and admits the plate below it, the guide piece assisting in the punching of the first hole. It is also a useful tool for making notches and for cross cutting long plates; in its absence this is usually done by punching a line of contiguous rivet holes, which, of course, results in a ragged and irregular edge.

Art. 535. A **beam-bending machine,** combined with angle shears and a horizontal punch, is shown in Fig. 7, Plate 115, and one is shown in the diagram, Fig. 2, Plate 95. The action in bending a bar is evident: the ram R (Fig. 2) advances and recedes through a fixed distance, and according as the adjustable pieces PP are screwed in or out (by the hand wheels W) a greater or less curvature is impressed on the bar. A useful application of the machine is shown in Fig. 3, Plate 80, wherein angle bars may be slightly bevelled, close or open, when cold; the loose, iron slabs SS are forced together by the advancing ram, so that an angle bar, placed between them as shown, may be rapidly bevelled, by a fixed or varying amount. The application is particularly useful in the case of angle lugs or gunwale bars which require only a slight bevel.

Art. 536. Plate-bending rolls and their uses are illustrated in Figs. 4, 5, and 8 to 13, Plate 95. The two lower rolls are made to revolve (in the same direction and at the same speed) by an attached engine or belt gearing. The top roll runs idly, and the plate is fed through by the movement of the lower ones. Either, or both ends of the top roll may be raised or depressed by screw gearing; in small or old-fashioned machines this gearing is worked by hand, but in those of modern design by belt gearing or by an independent small engine or electric motor, the motion being controlled from either end of the rolls, and, of course, quite independently of the main driving engine. When one end only of the upper roll is raised or depressed, the distance between the end bearings (measured along the roll) increases, and the journals become skewed, and, to meet this, the self-adjusting, cylindrical bearing-block shown in Fig. 7 is employed.

Bending rolls may be of any length up to about 36 feet. A convenient machine has rolls 26 feet long, and is capable of dealing with 24-feet shell plates, for, of course, when a plate is rolled diagonally, it must, to clear the end standards, be somewhat shorter than the rolls. Most machines are designed with sufficient strength to bend transversely, when cold, full-length plates having a thickness up to $1\frac{1}{4}$ or even $1\frac{1}{2}$ inch. The bottom rolls, if shorter than 26 feet, are usually of cast iron, hollow, with a forged spindle; if longer they cannot be cast, in which case they are solid steel forgings, drawn down from a large ingot. They are supported against deflecting pressures by "friction rollers," at two or three points in their length (as shown in Fig. 9, Plate 95); and, as in their case, therefore, special strength is not necessary, they may be of small diameter, about 18 inches, even in the largest machines. The top roller, on the other hand, is usually only held by its end journals, and, consequently, when bending long or thick plates cold, it may bend considerably, or even break; to secure, therefore, the necessary strength (combined with a moderate diameter), it is made of solid forged steel, from 24 to 33 inches diameter.

The bending effect of the rolls does not extend right out to the edges of the plate. This will be evident from Fig. 8, Plate 95, where it will be observed that, when the plate has passed through to the extent shown, the top roll ceases to exert any further bending pressure. It is evident that the smaller and closer together the lower rolls, the smaller will be the breadth of the unrolled marginal part, but, of course, a reduction in the diameter of the lower rolls requires greater strength in the upper one, for the shorter span of the plate below it necessitates a greater bending

pressure. The method adopted in practice for bending the marginal part is to place a narrow slab of wood, or a bar of convex iron on the plate near the edge, as shown in Fig. 9, so that the upper roll by taking contact with it, may give the necessary local pressure. In the case of thick boiler plates, the incompleteness of the circular form produced by the bending rolls is a serious matter, and, accordingly, in many cases these plates are not rolled, but are shaped in a hydraulic bending press.

The tendency of the top roll to spring upwards in the centre when bending a long plate transversely is objectionable, in that the curvature impressed on the plate is smaller at the centre than at the ends. This is usually provided against by making the diameter of the roll about 1 inch greater at the middle than at the ends, *i.e.* by making it slightly barrel shaped, in which case an upward deflection of half an inch would result in a perfectly straight lower edge. A machine is shown in Fig. 8, Plate 115, in which deflection of the upper roll is prevented by a powerful girder, placed above and moving in one with it, friction rollers being interposed, as shown in Fig. 5, Plate 95. This design is also advantageous in that it permits of a small, easily forged, upper roll, capable of producing a sharp local curvature, close to the edge, but, of course, the beam may sometimes interfere with the rolling of tube-like plates. When rolling heavy plates, the slight barrel shape of an ordinary top roll is insufficient to secure the same curvature from end to end, and in such cases the pressure at the central part is increased by laying sheet iron or thin slabs of wood on this part of the plate, and rolling them through with it. Long plates which require a sharp transverse curvature from end to end, are sometimes slightly heated, in which case, as the top roll does not bend it produces the same curvature throughout; to work plates in this way, however, at a low heat, is objectionable (Art. 561).

The **bending rolls are used for other purposes** besides the ordinary one of rolling plates. They may be employed for knuckling the ends of lapped plates, stem plates, etc., by laying a short piece of convex bar on the line of the knuckle (curved, if the knuckle is curved) and rolling it in with the plate; or a sharp bend near the edge, with a curved knuckle, may be impressed, as shown in Fig. 10, Plate 95, by placing a stout iron bar, say 2 feet long, at the knuckle, and advancing the plate until the upper roll bears upon the bar and bends the plate, then backing it out, shifting the bar along, and again advancing the plate, so as gradually to flange it to the proper bevel and curvature; to prevent slipping, pieces of wood must be inserted above and below as shown. They may also be employed as a bending press, by using only the depressing force of the top roll; a boss plate, for instance, may be roughly shaped in this way, by heating it, placing it below the top roll, and depressing one or both ends so as to mould the plate to shape. Or they may be adapted for flanging all sorts of plates, by tap bolting to the top roll a longitudinal T bar, which, when the roll is depressed, takes contact with the plate and bends it down between the lower rolls (Fig. 12). Or an unattached angle bar may be placed between the plate and the top roll as shown in Fig. 11. Plates up to about $\frac{1}{2}$ inch in thickness, such as tank margin plates, may be flanged cold in this way, but thicker ones, such as garboard plates, must be heated. In the case of thin plates, a sharp, well defined knuckle may be secured by laying a large-flanged angle bar between the lower rolls, to act as a sort of die (Fig. 13). The efficiency of the bending rolls in the above respects depends, of course, on the power of the depressing gear; in some this is too small for anything but light work. A convenient method of flanging small thin plates is to cut a deep, narrow, longitudinal slot in one of the

lower rolls, so that when the edge of the plate is inserted in this (Fig. 4), and the rolls are put in motion, the projecting part of the plate, when it comes in contact with the upper roll, is bent over with a sharp knuckle.

Art. 537. Plates as delivered from the steel works are never quite fair and flat, but are more or less bent, twisted, and buckled. The usual characteristic of a buckled plate is a flat central part and wavy margins, the length measured along the former being less than that measured along the latter. This peculiarity is more marked in thin plates, and is due to inaccuracies in the cylindrical form of the rolls at the steel works, or to unequal rates of cooling after the rolling (Art. 569). Buckled or unfair plates are flattened before fitting in the ship, in a machine known as a "**mangle**," "**plate straightener**" or "**flattener.**" One of these is shown in Fig. 1, Plate 115, and in section in Fig. 6, Plate 95. The three lower rolls are driven in the same direction and at the same speed, the four upper ones run idly, and may be raised or lowered simultaneously by means of one large hand wheel; the two end ones, however, may be adjusted separately, by separate hand wheels. The plates are mangled cold; if heated they would stretch, and in cooling might again become buckled. One is shown in process of mangling, and it will be observed that, as it passes through the machine, a series of ever-changing, wave-like undulations is impressed upon it, the effect of which is to stretch the flat or taut portions of the plate, and thus obliterate their drawing or buckling effect on the margins. The extent of the stretching effect depends, of course, on the pressure of the rolls and the number of times the plate is passed through. Ultimately, when the plate is withdrawn, the pressure of the last top roll is so adjusted as to neutralize the bending effect of the one next it, so that the plate may emerge straight.

Some modern plate flatteners are sufficiently large and powerful to deal with $1\frac{1}{2}$-inch plates, up to 8 feet in breadth, such as may be employed for the protective decks of warships, but ordinary machines are not usually capable of dealing with plates thicker than about $\frac{3}{4}$ inch, or broader than 5 feet. Thick plates are not often buckled; they may be bent and twisted, but such deformation, and even slight buckling, may be eliminated by passing them backwards and forwards through the ordinary bending rolls, turning them upside down after each pass, so as to reverse or eliminate the curvature. It is advantageous that a plate straightener should be strong, so that when fairing broad or thick plates, the rolls may not spring away from their work. In a weak machine the bending of the rolls may entirely nullify their fairing effect, for the pressure at the middle of the plate, just where it is wanted, becomes small, and that at the margins, where not required, great. In practice this is met by rolling in with the central part of the plate, sheet iron, or thin slabs of elm, so as to concentrate the bending and stretching effect where most required. If a thin plate is so much buckled as to resist the flattening effect of the mangle, it may be faired by heating it all over, hammering it flat on the slabs, and then allowing it to cool uniformly, for which purpose the margins—which tend to cool more rapidly than the central part—may be covered with ashes, or the cooling of the central part may be expedited with water or by other means. In some cases, after fairing a thin plate as far as possible in the mangle, those parts which are still drawn or taut may be extended by hammering on an anvil or slab. Shell plates and others are usually mangled as a final operation, but plates which are very much buckled should be flattened before templating, for the stretching effect may spoil the coincidence of the holes.

Art. 538. A **garboard-flanging machine** for flanging plates by hand

power when hot, is shown in Fig. 1, Plate 95, as also its mode of operation. In modern establishments, hydraulic cold-flanging machines have entirely superseded the older hot-flanging machines. Formerly, of course, with iron plates, heating was essential, and as the plates were bent parallel with the grain, an extra good quality of iron had to be employed for the garboard strakes. The red-hot plate P is clamped in place by the beam B, which is forced down upon it by a wedge W, passing through a standard, one at each end. The beam is raised and lowered, expeditiously, by long levers, L. It is essential that there shall be no delay in fixing the plate in place, otherwise it might become too cold and stiff for the subsequent flanging. The flanging roller R is raised or lowered by winch handles H, working a train of geared wheels as shown; in some modern machines hydraulic power is employed, which, of course, on account of the greater expedition, is very advantageous; in such machines, however, the power is so great that the plates may be flanged cold, so that they are really *cold-flanging* machines. Either end of the roller may be raised or lowered more than the other, so as to vary the bevel of the flange from end to end of the plate. The required bevel is obtained by set-irons, one for each end, bent previously in the berth the plate is to occupy in the ship. The radius of knuckle may be increased or diminished to suit thick or thin plates, by adjusting the roller out or in by the screw S. Owing to the imperfect clamping effect of the beam, the plate is apt to slip under it, so that the flange is usually made an inch or so broader than necessary, and is sheared as required subsequently. The contact of the hot plate with the cast-iron material of the machine and clamping beam, tends, by local heating and expansion, to cause the rupture of these parts, and, accordingly, to prevent undue heating, both parts are cast hollow, so that they may be kept full of water, and as it is important that the lower part should always be full right up to the top, it should be kept under a head of water, by means of a cistern placed above it. Many machines have been broken through neglect of this precaution. Some of the later ones are built of steel plates and bars, which, of course, do not, like cast iron, fracture when locally heated. The sketch shows how, after the flanging, the shell portion of a garboard plate may be curved transversely.

Art. 539. A hydraulic **cold-flanging machine** is shown in Fig. 6, Plate 115, and in section in Fig. 4, Plate 83, its mode of action being also indicated. The plate about to be flanged is clamped firmly in place, as shown in Fig. 4, by the sliding wedge piece W, which is tapered longitudinally, and is forced on end by a small ram. It will be noticed that the lip round which the plate is bent, projects beyond the lower clamping piece P (Art. 558). The roller R, which is actuated by two hydraulic rams, may be raised, or lowered, one end more than the other, so as to make a flange having a bevel varying from end to end; this, of course, is necessary in the case of the end garboard plates or dished keel plates. Bulkhead plates are often double flanged, as shown in Fig. 4, the small flange being made first. A **joggled flange** (A, Fig. 4) may be produced by introducing two liners of suitable thickness, one below and one above the portion of the plate about to be flanged (but not over each other), when the clamping of the plate in place produces the required joggle. This is useful in the case of flanged floors when the tank-top plating is not joggled, and in some flanged bracket plates. When flanging floor or bulkhead plates, a portion at each corner (see B, Fig. 4) is usually removed before the flanging (Figs. 1 and 5, Plate 23, and Plate 102). Sometimes this is done by punching contiguous small holes, in which case, as the edge is rendered brittle, the knuckle is very apt to crack at this point; to avoid this, therefore, the

corner should be removed by a manhole punch, whose shearing action makes a clean cut, and does not cause so much brittleness in the steel. Some cold-flanging machines are capable of dealing with plates 36 feet long. Plates longer than the machine may be flanged by doing the work gradually, shifting the plate endwise after each part of the edge is more or less perfectly flanged, then going over it a second time.

Art. 540. A hydraulic **manhole-punching machine** is shown in Fig. 9, Plate 115; the punch and die are detachable, various sizes being provided for holes of different dimensions. It may also be used for flanging and joggling purposes. Three kinds of punches are shown in Figs. 15, 16, and 17, Plate 95. It will be observed that, as in each case the face is bevelled, the action is a shearing one, which, of course, causes a smaller stress on the machine. The spiral-faced punch shown in Fig. 15 tears the part removed, and is less efficient than the others. An ordinary punching machine is sometimes designed to punch small manholes in thin plates; as it is quick in action, it is convenient for punching the numerous lightening holes in the floor plates of a cellular double bottom; it may be made to produce holes of large size, by punching two or more contiguous small ones. Many small yards are not equipped with a manhole punch, in which case the necessary hole is made by punching consecutive rivet holes (Fig. 14), the sharp points being subsequently chipped off by hand.

Art. 541. A hydraulic hand punch, known as a "**bear**," is shown in outline in Fig. 3A, Plate 95. This machine is used for punching odd holes in the framework of the ship, for, although heavy and cumbrous to move about, it is much more expeditious than the ratchet drills otherwise employed for such work. About twelve strokes of the lever handle are sufficient to punch a hole through $\frac{1}{2}$-inch material. Electric and pneumatic drills are now often used for drilling plated decks for the sheathing bolts; and in repair work, where numerous holes may have to be made in place, or shell rivets removed by drilling through their countersunk heads (Art. 319).

Art. 542. A **plate-edge planing machine** is shown in Fig. 2, Plate 115. The plate is clamped in place by the screws under the beam. A thin piece of timber is usually introduced between the plate and the table, to give frictional resistance against the tendency of the knife to shift the plate, which may be further provided against by inserting pins in the holes in the table. In some modern machines, small hydraulic rams take the place of the clamping screws, thus saving both time and labour. The end supports of the clamping beam are so formed as to permit of plates longer than the machine being fixed in place. The cutter is propelled from end to end of the machine by a long screwed spindle, working through a nut in the carriage carrying the cutter; and it may be revolved on its own axis through 180 degrees, so as to cut while moving in either direction. These machines are usually driven by belt gearing, stops being provided to shift the driving belts, and thus automatically reverse the movement of the cutter. An **angle planing machine** is shown in Fig. 18, Plate 115. The bar is drawn through by rollers, while adjustable cutters plane simultaneously the two edges or toes (Art. 323).

A **plate joggling machine** (Art. 113) is shown by the diagram in Fig. 3, Plate 95. The lower drum D is machine driven, and as the plate travels between the two drums, the collars C impress the required joggle, the depth of which may be varied by raising or lowering the upper drum, and the distance from the edge, by moving out or in the block B. An ordinary punching or shearing machine may be adapted for joggling plates, as shown in Fig. 1A, Plate 95. Fig. 10, Plate 115, shows a **hydraulic**

press, designed **for joggling angle bars** cold, as is commonly done in the case of the frame and reverse angles within a double bottom; the joggling is done as shown in Fig. 8, Plate 82. It may also be employed for joggling plate landings, punching manholes, or for flanging small plates, such as the intercostal plates of a cellular double bottom; in the case of plates longer than the stamp, the flanging must be done in detail.

Countersinking machines vary in design; formerly, when plates were small, the spindle was often fixed, a design which requires the plate to be shifted for each hole; in modern machines the spindle is made adjustable, usually by placing it on a radial swinging arm. An excellent machine of this kind is shown in Fig. 13, Plate 115; the tool may be adjusted with a touch of the handle, and commands a large area of plate.

CHAPTER XL.

Art. 543. An important matter in shipbuilding is the **preparation of the slipways, or berths.** In yards where the ground is hard and solid, the keel blocks for any particular ship may be laid in whatever line is most suitable, having regard to the size of the ship, the launching facilities, and the space required between it and adjoining vessels under construction or about to be built. Most shipyards are divided off, more or less permanently, into so many berths. If the ground is soft, it may be incapable of sustaining the weight of a large vessel, in which case, to avoid subsidence, **piles** must be driven in the line of the keel blocks and launching ways. Such work is costly, but, of course, if well done and sufficiently extensive, it need only be done once. In each shipyard experience accumulates as to the weight-sustaining capabilities of the ground, and those berths where it is found to be hard and good, or has been made so by piling, are reserved for heavy vessels. The building slip for a modern Atlantic liner, or armour-clad battleship, is always extensively piled, for not only is the weight excessive, but the value at stake is too great to warrant any risk. The ground is specially severely tried by an armour-clad, because both it and its launching cradle are short compared with the launching weight.

During the building, the keel blocks take the greater part of the weight, and the bilge blocks and shores the remainder (Fig. 3, Plate 96). The most critical pressure occurs during the launch, for then the whole weight of the hull is transferred to the two strips of ground under the launching ways (Fig. 8, Plate 97); and as the weight, when she slides down, is rapidly transferred from one piece of ground to another, a severe pressure is imposed on ground which previously has suffered none. A small subsidence during the launch is not unlikely to have disastrous consequences, for the resulting local pressure and friction between the ways may cause the vessel to stop, perhaps in a critical position. A similar subsidence during the building would be unimportant, for the various shores and keel blocks are under constant inspection, and are hardened up and adjusted as required.

The softness or hardness of the ground may be tested roughly by thrusting into it a slender rod of iron; if this can be forced down several feet by the hands alone, the ground is unfit to sustain any weight without piling. In most shipyards the ground is able, without piling, to sustain, with little or no subsidence, the weight of ordinary vessels. It is usually found necessary, however, to pile the lower end or *breast* of the slipway, between high and low water (Fig. 1, Plate 98), for an excessive pressure occurs here during the launch, and, owing to the steep slope of the breast and the wash of the tide, its solidity and permanence, if unpiled, is more or less doubtful. Excessive pressure may occur here during the launch, because, when the greater part of the cradle has left the ground ways, a corresponding part of the weight of the hull may not be waterborne; and the pressure, moreover,

may be intensified by localization, due to the hull pivoting about the end of the ways, as shown in Figs. 3 and 4. An arrangement of piles commonly adopted is shown in Fig. 8, Plate 97. The cross rows are from 4 to 6 feet apart. If specially heavy ships are to be built, the outer piles, which fall under the launching ways, are duplicated. The horizontal logs distribute the sustaining power of the piles and form suitable foundations and fixtures for the keel blocks, launching ways, and shores. Sometimes, in order still better to distribute the sustaining power of the piles, fore-and-aft logs are laid on their tops, and cross logs upon these. When all the ground of the slipway is bad, or when it is intended to build vessels of great weight, the same system of piling is carried all fore-and-aft, with the omission, perhaps, of the central and outer piles alternately in alternate transverse rows. In yards where only light vessels are built, piling even at the ends of the slipway may be dispensed with. In such cases, to distribute the weight, cross logs may be laid (square to the slipway) flush with the ground, being held in place by angle bars, driven down alongside and bolted to the logs. If the breast is exposed to the wash of the tide, stone sets are laid between the logs.

Piles are usually hewn logs about 15 inches square, pointed and shod with iron; sometimes, in less substantial work, fir stems, about 10 inches diameter at the butt, are employed. They should be long enough to enter the gravel subsoil, which may be at any depth up to about 50 feet. They are driven sufficiently solidly when a blow from a 15 or 20-cwt. monkey, falling about 20 feet, fails to move them more than about half an inch. A series of piles being driven, their tops are sawn off, and the cross logs laid on their ends, to which they are usually fastened by long driving bolts.

Art. 544. Consider now the procedure of **laying the keel blocks.** The position and inclination of the keel are governed by the requirements of the launch. Vessels built on narrow rivers must be inclined to the breast, so that they may be launched up or down the stream, and thus allow sufficient clearance for pulling them up after they have left the ways. On good ground the blocks are sometimes placed directly upon it (Fig. 6, Plate 96), but in most cases, to distribute the pressure, stage planks are first laid all fore-and-aft, as shown in Fig. 14, or only under each block, as shown in Fig. 2, Plate 97. If the ground, being unpiled, is doubtful, or if a large vessel is to be built, a more secure foundation is made by laying short stage planks athwartship close together all fore-and-aft, and superposing three fore-and-aft logs, as shown in Fig. 7, Plate 96. Having prepared the foundation, the lower blocks are laid all fore-and-aft, from 4 to 6 feet apart (as shown in Fig. 1, Plate 97), and to every third or fourth an upright batten is nailed, in the line of, and standing rather higher than, the keel. To suit the declivity of the launching ways, the keel also is inclined, usually about $\frac{9}{16}$ inch to the foot (in yards in which the ground has a large slope this may be greatly exceeded). Assuming $\frac{9}{16}$ inch per foot to be the declivity, a straight-edge about 20 feet long is prepared, having nailed upon its side a short, supplementary straight-edge, inclined to the edge of the first by $\frac{9}{16}$ inch to the foot, as shown in Fig. 1, Plate 97. Starting from 'midships, the straight-edge is held between and against two of the upright battens, one end to a pencil mark on the aftermost, say, 3 feet 6 inches above the ground, and the other at such a height that a spirit-level placed on the supplementary straight-edge indicates the horizontal; when so held the straight-edge is necessarily inclined at $\frac{9}{16}$ inch to the foot, and the position of its edge is marked with pencil on the other batten. It is then transferred to the next pair of battens, and the third one marked in the same way. When all are marked they are cut square across at the marks, and a wire, resting on their tops, stretched tightly from end to end of the

slipway. If the work has been carefully done the wire will be perfectly straight, and may be taken to represent the lower edge of the keel. The keel blocks are now built up to within 3 or 4 inches of the wire, and top pieces fitted of just the proper thickness to touch it. As a guide in laying the keel, the transverse position of the wire is marked across an edge of each top piece, or on the upright battens, which may be left in place.

Keel blocks are simply cuttings from pine logs of any kind, from 18 inches to 12 inches square. To distribute their pressure on the ground the bottom one should be long, say, 4 or 5 feet, the upper ones may be quite short. The method of arranging the blocks on the north-east coast of England is shown in Fig. 2, Plate 97, and that adopted on the Clyde and elsewhere, in Figs. 1 and 4. It will be observed that the former appears to be less substantial than the latter, but this circumstance is met by the greater stability of the blocks and by the use of numerous bilge blocks. When the declivity of the vessel's keel is considerable, or when the keel blocks are high and small, the latter might tend to trip, and to avoid this, fore-and-aft tie planks are placed between them, as shown in Fig. 3, and diagonal shores introduced, as shown in Fig. 2. Whatever the arrangement of the keel blocks, their size and spacing varies with the weight of the vessel; in a large one they must be stout and closely spaced. They require to be removed (one or two at a time) once, at least, during the building, so that the keel may be riveted and caulked, after which they may be placed closer together, the better to support the increasing weight of the hull; and two tapered pieces of hard wood are introduced immediately below the keel, to permit of adjustment, and facilitate their removal at the launch.

The **height of the keel above the ground** depends on circumstances; to permit of the bottom plating amidships being conveniently riveted, it should be about 4 feet above the ground, and, accordingly, if the slope of the building slip and of the keel are the same, this would be the height all fore and aft. In some yards, however, the ground has very little slope, in which case, to permit of a sufficient declivity in the launching ways, the forward part of the keel must, necessarily, rise well above the ground, for if the vessel's fore-foot were below the level of the ground ways (whose declivity requires that they shall be well above the ground at the forward end, and close to it at the breast), it might, when travelling down, take contact with the breast. In some yards, having slipways with little slope, the fore-foot of a long vessel may be elevated 20 feet or more above the ground. The most suitable height and inclination of the keel are usually decided by experience gained in building and launching previous vessels, and, in the absence of experience, they may be readily ascertained by making a profile plan of the berth, showing the vessel and launching ways in position.

Art. 545. Consider briefly some of the principal matters in connection with **launching.** There are two sets of launching ways: the *fixed*, *ground*, or *standing ways*, and the *sliding ways or bilge logs* (Figs. 8 to 15, Plate 97, and Fig. 1, Plate 98). The latter form the lower part of the cradle, the upper part of which consists of making-up or filling pieces, formed of cross wedge-shaped blocks or fore-and-aft planks or balks of timber, neatly fitted to the vessel's shell plating. The ground ways are laid at the required height and inclination, on closely spaced supporting blocks, or fore-and-aft logs, stage planks being usually laid first as a foundation on the surface of the ground; and they extend down to, or nearly down to low-water mark, so that their ends at high tide may be covered by from 3 to 6 feet of water (Fig. 1, Plate 98). To guide the sliding ways as they move over the ground ways,

there is a projecting ledge piece or *ribband* (Figs. 11 and 12, Plate 97), bolted either to the inner edge of the sliding ways, or to the outer edge of the ground ways; the latter position involves a longer ribband, but it has the advantage of preventing, to some extent, the escape of the lubricating grease. On the north-east coast of England a ribband is usually dispensed with, the ground ways being formed with a transverse hollow, and the sliders with a corresponding convexity (Fig. 9). Originally this was done, no doubt, for the purpose of retaining the lubricant, but as it is a difficult matter so to form the two curved surfaces that they may fit accurately upon each other, there is a greater likelihood of friction. Another formation, in which a ribband is dispensed with, is shown in Fig. 13; an essential matter here, is that the depth of the check must be identical in both the fixed and sliding ways, all fore and aft.

The ways are either of yellow or pitch pine, but, for heavy vessels, American elm or oak is sometimes employed, either all fore and aft or only for the outer lengths of the ground ways and the upper lengths of the sliders, these particular lengths having to bear the most pressure. Sometimes pine ways are faced with elm. Their size varies greatly; large shipyards are usually provided with two sets of ways, one for small vessels and the other for large; the former may be composed of single logs, perhaps 15 inches broad by 9 inches thick; the latter of two logs bolted together, having a combined breadth of 24 or 30 inches, and a thickness of 12 or 15 inches (Fig. 12, Plate 97). In yards which employ hollow ways, supplementary flat ones are laid alongside when launching extra heavy vessels (Fig. 10). An increase in the thickness of the ways is advantageous in that, as it is accompanied by greater rigidity, inequalities in the support are better bridged over and distributed. In launching any particular vessel, the breadth of the ways should be such that the pressure on each square foot of their surface (*i.e.* the weight of the ship divided by the total area of the sliding ways) does not exceed $2\frac{1}{2}$ tons. Many vessels have been launched with a pressure as great as 3 tons, and even greater; but in such cases there is usually early evidence of excessive friction, the grease smoking and charring with the heat. In the large majority of launches the pressure is less than 2 tons. The ways employed for launching warships and large Ocean liners are very broad; those for H.M.S. *Niobe* and *Ocean* were each 5 feet broad, the respective launching weights being 6300 and 7110 tons, and the pressures 1·84 and 2·5 tons per square foot; the ways of the latter vessel were teak faced. The breadth of the ways used for launching the s.s. *Oceanic* was $4\frac{1}{2}$ feet; the launching weight being about 11,000 tons, and the pressure per square foot, 2·35 tons.

The different lengths of large ground ways are usually connected, as shown in Fig. 14, Plate 97. The sliding ways are butt-jointed and tied together by chains, so that the cradle may not break in two, lengthwise, through local friction or the restraining force of the dog shores; and their outer ends should be moored to the deck by ropes or chains to prevent them from digging into the ground at the bottom of the river. The ground ways are shored sideways to prevent transverse movement (Fig. 8), and fore and aft to prevent them from moving down with the ship, should excessive friction occur between them and the sliders. The port and starboard ways must be in the same or parallel planes, otherwise the vessel would heel from side to side as she passed over them.

The ground **ways are usually laid with a fore-and-aft camber** (Fig. 1, Plate 98). The amount varies in different yards, a round-up of 2 feet in 400 is perhaps the maximum, 1 foot is probably the average. The curvature should be uniform from end to end, *i.e.* it should be that of

the circumference of a large circle; sometimes, however, it is actually increased towards the lower end, which means, of course, that the cradle, when it comes to this part, must cease uniformly to support the vessel, the sliding ways bearing on the standing ones with varying pressure throughout their length. In yards where an increasing camber is adopted, the declivity is generally larger than usual, so that the accompanying great speed of the launch discounts any prejudicial effects of friction. Camber is not essential; in some cases there may be none, and in others it is reversed, the ways being laid with a hollow. The latter plan is useful when the vessel has a long way to run, and when the depth of the water into which she is launched does not much exceed her draught. It is also useful in the case of long, light-scantlinged, shallow-draught vessels, of the torpedo-boat or river-steamer class, where, to avoid longitudinal stress, it is desirable that they should enter the water without any pivoting movement about the ends of the ways, such as is illustrated in Figs. 3 and 4, Plate 98.

Camber is advantageous in that it permits of an increasing declivity, so that while the upper part of the ways may drop only about $\frac{1}{2}$ inch to the foot, the lower part may drop $\frac{3}{4}$ inch, or 50 per cent. more. It is advantageous that the declivity at the upper part should not much exceed $\frac{1}{2}$ inch to the foot, for this is sufficient to start the launch; it permits of a comparatively small declivity in the vessel's keel, and as a rule it does not greatly depart from the natural slope of the ground, which, in most yards, is fairly level at the upper part, with an increasing slope towards the breast. With so small a declivity at the upper part, a considerable increase is required towards the bottom, in order that the ends of the ways may be sufficiently immersed, and so that their total drop may be sufficient to lower the vessel from her elevated position on the building slip to her low level when afloat; in large vessels the total drop may be as much as 30 or 40 feet. Further, when the depth of water at the ends of the ways is limited, a considerable final declivity is necessary to prevent *tipping* (Fig. 3, Plate 98), and to maintain the vessel's motion when her stern enters, and is impeded by the water, so that she may not linger during the critical phase when the cradle is about to leave the end of the ground ways. Camber is also useful to a certain extent as a provision against slight subsidence of the ground, for should this occur the ways would merely become straight; if they were straight to begin with, they would become hollow, but, of course, either deformation would be objectionable.

The most critical period of a launch occurs after the vessel's centre of gravity, or about half her length, has passed over the ends of the ground ways, for if the immersion of the after part is insufficient to buoy it up, the entire hull may **pivot about the ends of the ground ways**, as shown in Fig. 3, Plate 98. The vessel is then said to "tip;" the tendency is a dangerous one, for, as her bow rises out of the cradle and the weight becomes concentrated at the ends of the ground ways, the intense local pressure may damage her bottom, and the disturbance of the cradle, and the very localized and imperfect nature of the support may cause her to crush down through the cradle, strike the breast, and remain at a standstill in a most critical position. The tendency to tip may be provided against either by extending the ways further into the water, so that their ends may be more deeply submerged, or by increasing their declivity (Fig. 4, Plate 98), for, as both methods secure a deeper immersion of the hull when partly clear of the ground ways, there is a larger buoyant moment against tipping. It might also be provided against by filling the fore peak with water, for as this has the effect of shifting the centre of gravity of the hull forward, the stern must run further off the ways and be more deeply submerged before the occurrence

of the tipping phase. This method is objectionable, however, in that it increases the pressure at the forward end of the cradle when all but this part has left the ground ways. A sufficiency in the declivity may render comparatively unimportant the depth of water at the ends of the ways; for although, when launching large vessels, a depth of 4 or 5 feet is usually desirable, yet, if the declivity is ample, successful launches may be made with half as much. Many vessels are launched with no water at all on the ends of the ways, but in such cases the breast terminates in a steep bank or wall, so that there is no chance of the fore-foot being injured by striking the ground when the cradle drops off the ends of the ways. It may be readily ascertained by calculation whether or not, with a certain declivity and depth of water at the ends of the ways, the vessel will have any tendency to tip.[1]

As a vessel progresses down the ways, there arrives, finally, a period when her stern receives so much buoyant support that it lifts, and causes her to **pivot about the forward end of the cradle, or fore poppets** (Fig. 4, Plate 98). In very fine-lined vessels the poppets consist of vertical timber props, ribbanded together (Fig. 2); in full cargo vessels the ends of the sliding ways form the poppets. In fine-lined vessels the poppets give but a poor support, for, owing to the V form of the bow sections, they are readily wedged outwards by a small excess of downward pressure. When the above pivoting action takes place, the bow of a fine vessel usually slips down through the cradle; the circumstance, however, is generally unimportant, for it occurs when the cradle is nearly clear of the ground ways, and as the vessel is in rapid motion and the downward plunge of the bow through the cradle is slow, the cutway fore-foot usually clears the breast before it descends to its level. In large, fine-lined vessels special provision may be made against the fore-foot breaking prematurely through the cradle, by tying the heads of the port and starboard poppets together with chains or plate ties passed below the fore-foot (Fig. 2), or by riveting temporary lugs or shoes to the shell plating around the heads of the poppets; also, by carrying the ground ways well out beyond the end of the breast, or by digging a channel between their ends, so that the descending fore-foot may clear the ground. Pivoting action is only dangerous when it occurs prematurely, before the fore-foot has approached sufficiently near the ends of the ground ways (Fig. 4), and this may happen if the final declivity is too great, or if there is too much water on the ends of the ways. In the case of long, shallow-draught, light-scantlinged vessels, such as torpedo boats and paddle steamers, it may be objectionable in causing considerable longitudinal stress in the structure of the hull; such vessels, therefore, should be launched on ways of small declivity, carried well out below the water, conditions which may be secured by giving them a hollow camber.

The **distance between the ways**, centre to centre, is usually about one-third the vessel's beam; in a large, heavy vessel the precise distance should be decided by the structural arrangement of the hull, for if there are side longitudinals or keelsons it is well that these should take the pressure of the ways; it may also be decided, of course, by the position of the yard piling. In vessels of great weight and wide frame-spacing, shores and fillings are sometimes fitted within the hull, to distribute the supporting

[1] Many interesting matters and data, in connection with launching and launching calculations, will be found in the following papers and the discussions they occasioned: Mr. J. W. Shepherd, and Mr. J. D'Anguilar Samuda, *Trans. Institution of Naval Architects*, 1877. W. Denny, *Trans. Institution of Naval Architects*, 1882. H. G. Gannaway, *Trans. North-East Coast Institution of Engineers and Shipbuilders*, 1886–87. H. R. Champness, *Trans. Institution of Mechanical Engineers*, 1899.

effect of the cradle from one part to another, and reinforce the shell against excessive local pressure. In warships this is particularly necessary, because of their great weight, wide frame-spacing, and slender scantlings. The closer together the ways, the more extensive the support received from the cradle, for it may be carried further forward and aft before it leaves the flat part of the bottom, and, by placing the fore poppet nearer the stem, the tendency to premature pivoting is minimized. In long, fine-lined vessels a very considerable portion of the hull at either end may overhang the cradle, in some cases as much as 70 feet. With flat ways, in which the ribband is on the outer edge of the standing ones or on the inner edge of the sliders, the distance between the standing ways is usually increased from 1 to 2 inches towards the breast, to allow for any slight displacement of the cradle during the launch, and to give additional side play should the vessel's stern, when water-borne, drift laterally with the tide (a similar effect cannot be secured with hollow ways); in any case, of course, the ribbands have about $\frac{1}{2}$ inch of clearance from the side of the ways.

Two or three days before the launch, the cradle, which has usually been fitted in place temporarily, is taken adrift, and the surface of both the sliding and standing ways (the latter in way of the cradle only) covered thickly with **melted tallow** (usually Russian tallow, of the best quality); when this has hardened, it is smeared with **soft soap**, after which the sliding ways and the various making-up pieces of the cradle are replaced. Before greasing the ways they are scraped clean; if planed they should be planed across the grain, for the resulting somewhat rough surface gives a better hold for the tallow. On the morning of the launch the exposed outer parts of the standing ways are greased and soaped, and the cradle is "set-up" by driving, with battering rams or mauls, long tapered wedges between the making-up pieces (Figs. 8 and 9, Plate 97). The setting-up of the cradle takes some of the vessel's weight off the keel blocks, which are then split out.

Until the moment of launching, the sliding ways are locked to the ground ways by a **dog-shore** or **dagger**, one on either side at the forward end, as shown in Fig. 15, Plate 97, and Fig. 1, Plate 98. A large, heavy vessel, when free of all keel and bilge blocks, may exert an intense compressive force on the dog-shores, and, perhaps, by crushing them, launch herself prematurely, with disastrous results. This is avoided in several ways: thus, it is usual to leave in a few of the keel blocks, and a pair of bilge blocks, at the forward end, and the sliding and ground ways may be dogged together at various points, and in very large vessels an auxiliary pair of dog-shores may be introduced at the after end. These extra securities are cast adrift at the last moment; as a rule, the foremost keel blocks do not require to be removed, the vessel tripping them out of the way as she begins to move. In some yards on the north-east coast of England dog-shores are dispensed with, the ship, after the removal of the keel blocks and shores, being held in place by numerous bilge blocks; these are then removed, working from the stern towards the bow, the ship usually beginning to move before the last pair on either side are removed. To facilitate their removal, and prevent damage should the vessel force herself past them, the upper parts are tapered fore and aft, as shown in Fig. 5, Plate 96. The heads of the two dog-shores are sometimes struck down independently, by sledge hammers, but, to ensure effective and simultaneous action, it is better, if there is sufficient room above them, to suspend over each one a small "monkey," or mass of iron, which may be released simultaneously by the cutting of a single cord. A substitute for the usual dagger or dog-shore is shown in Fig. 6, Plate 98. This is a useful

arrangement in the case of full vessels, where there may not be sufficient height to strike down the daggers. It is usually placed amidships. The ram cylinders on either side are connected by a pipe, another pipe being led to a force pump or hydraulic accumulator. To release the trigger or pawl, a cock has merely to be opened to let the water out of the ram cylinder. This contrivance [1] was used at the launch of the s.s. *Oceanic*, and is now in very general use for large vessels. In case the vessel should fail to start on the release of the dog-shores, it is usual to introduce a hydraulic starting ram (worked by a small, hand, force pump, or by pressure water from an accumulator), under the fore-foot or at the upper end of each sliding way, as shown in Fig. 15, Plate 97.

When launched in open water, the **vessel is brought up, when clear of the ways**, by dropping an anchor, which is slipped when the tug boat takes charge. When launched in a narrow river, she must be stopped quickly before her stern (or bow, if launched bow first) strikes the opposite bank, the keel being laid at such an angle, up or down the river, as will give sufficient clearance for pulling her up after she has left the ways. This is done by leading cables or wire hawsers from the bows or quarters, and attaching them to anchors buried in the ground or to heavy weights, or *drags*, composed of coils of chain or piles of plates, whose friction with the ground, as they are pulled over it, gradually brings the vessel to rest. If room permits, the latter is the better method, for a chain cable, when attached to a buried anchor, may receive so severe a jerk as to break it (this is not an uncommon occurrence), and the anchors tear up the slip-way. In many cases both anchors and drags are employed, in combination. On the north-east coast of England wire hawsers are largely employed for launching purposes, some being as large as 9 inches in circumference; as they are more yielding than a chain, they are less liable to snap. Vessels of moderate size may be brought up with two cables, which are passed through the hawse pipes and made fast inside, usually to a balk of timber placed athwart the fore hatch below the deck. Large vessels may require two or three pairs of cables, which are made fast to large eye-plates bolted on the vessel's side. On the north-east coast of England, where the channel in front of some yards is very narrow, and the launching declivity excessive, as many as eight cables may be employed, both wire and chain, all made fast to anchors, so that the vessel may be pulled up dead, before her bow is half her length clear of the ends of the ground ways; and in many cases the cables are all made fast on one side, near the stern, at the water-line, so that the vessel may be pulled round with her stern up or down the stream. On the Clyde, drags are preferred to anchors; their weight varies with the size of the vessel. Each cable is usually made fast to two, three, or four separate masses, each weighing from 5 to 15 tons, but with slack chain between, so that only one at a time is started; thus, immediately the vessel has left the ways, or before this in the case of a long heavy vessel, all the cables become taut and put in motion the first drags (*i.e.* those nearest the breast); about 10 feet further on, the second lot of drags receive a pull, and then again the third, so that the cables receive no severe jerk, and the constantly increasing friction pulls the vessel gently but quickly to a standstill. To hold the rudder amidships during the launch, its quadrant tiller is locked by shores, or in steamers it may be fixed below by a pair of ribbands, which also serve to lock the propeller, if this is in place and it is desired that it shall not revolve. In many cases neither the rudder nor propeller is fitted until after the launch.

[1] The invention of Mr. P. Phorson.

Vessels which are built on narrow rivers or canals must be **launched sideways**; on the North-American lakes this is the usual method, even with large vessels. A sketch of the general arrangement of a broadside launch is given in Fig. 5, Plate 98. To support the vessel uniformly throughout her length, numerous ways are required; they are usually placed at intervals of from 10 to 15 feet. A few of them have guide ribbands, and there are several dog-shores, which are let go simultaneously by falling weights, as indicated in the drawing. In order that the vessel may clear the ends of the ways, when brought up broadside by the water, she must be launched with very considerable velocity, and for this purpose the declivity of the ways at the outer ends may be as great as 4 inches to the foot. Where there is no tide, there may be no water on the ends of the ways, in which case the vessel is practically shot over the breast, or wall, into the water. The outer ends of the ways must all be in line, and parallel to the vessel's keel, so that she may clear them simultaneously. It may be observed that the s.s. *Great Eastern* was launched broadside-on.

CHAPTER XLI.

Art. 546. Iron appears to have been employed as a substitute for wood as early as 1820, but for many years it was only used in a tentative fashion, for canal barges and the like. By 1855 its use for sea-going vessels had become fairly common, and Lloyd's Register issued in that year their first rules for iron vessels. At first the iron supplied to the shipyards was of excellent quality, being both tough and strong, but later, when it was observed that iron hulls were immensely strong compared with those of wood, the natural tendency to cheapen construction resulted in a gradual falling off in quality, until, finally, the use of inferior, brittle material became common, the term "boat plates," currently used, being significant of very bad iron. Lloyd's rules required (and still require) the iron used in classed vessels to be of good, malleable quality, capable of withstanding a tensile stress of 20 tons with the grain, and 18 tons across it, but as tests were not enforced, the stipulation did not have the desired result of ensuring good material. The only test imposed was the mechanical treatment the plates and bars received when being worked into the ship, very many cracking during the process. Latterly, Lloyd's rules required that the makers of the iron should stamp their name on every plate and bar, and this had a good effect in maintaining a certain standard of quality. Although iron ships were thus often built of very poor iron, they nevertheless served their purpose well, the scantlings in vogue being sufficient to discount defects of quality.

Art. 547. Steel was first employed as early as 1859, for some high-speed paddle steamers.[1] This was ordinary **cast or puddled steel,** which, while possessing the high tensile strength of about 40 tons per square inch, was hard, brittle, and unreliable. It cost about £40 per ton, and its use, therefore, was confined to high-speed steamers, where the requirement of a light hull made strength in the structural material an all-important quality.

Mild steel of fairly good quality was first produced about 1873; it was used in that year in France, for the construction of warships. Both the *Bessemer* and *Siemen's* process were employed in its manufacture, the quality of the material made by either process being then much the same. Bessemer steel was made as early as 1863, but, owing to imperfections in the process, its mechanical qualities were for many years little better than those of cast or puddled steel, and as it was even more costly, its employment was confined to some three or four sailing-ships and a few light-draught paddle steamers. By 1875 great improvements had been made in the Siemen's process, and mild steel of excellent quality, little if at all inferior to that now employed, at once became available.[2] It was used in that year for H.M.S. *Iris* and *Mercury*, the first vessels built of mild

[1] Some interesting particulars of the first steel vessels will be found in a paper by Sir John Ravenhill, *Trans. Institution of Naval Architects*, 1881.

[2] A full description of this early mild steel will be found in a paper by Mr. Riley, in the *Trans. Institution of Naval Architects*, 1876.

steel in this country. As regards merchant vessels, it did not at first compete very keenly with iron, for although Lloyd's Register sanctioned its use, and allowed a reduction in scantlings of 20 per cent., its high price, and difficulties in securing prompt delivery, delayed its general adoption. As regards merchant vessels, the steel era may be dated from about 1878, for in that year eleven steel vessels were built, and in each succeeding year a rapidly increasing number.

Art. 548. Iron plates are made by hammering and rolling together numerous small pieces at a welding temperature. The welding is not absolutely uniform or perfect, for as the slag and impurities taken up during the puddling process (when the iron is soft and pasty) remain interspersed throughout the mass, they separate the particles of pure iron and preclude homogeneousness. The rolling operation, by drawing out the metallic iron, produces a fibrous texture or grain, the mass being composed of well-defined **longitudinal fibres**, whose imperfect cohesion due to the entangled impurities causes variations in the strength and ductility according to the direction in which the stress is applied. Thus, if a test piece is pulled *with* the grain, its fracture involves the fracture of every fibre, whereas if pulled *crosswise* some of the fibres, instead of fracturing, may only be separated. The strength of good iron when tested crosswise is usually about 10 per cent. less than when tested longitudinally, but when of inferior quality the difference may be much greater. Lloyd's rules specify a strength of 20 tons with, and 18 across the grain; the Admiralty require 21 tons with, and 18 across the grain, but, in the highest quality, 22 and 18 tons.

The **mechanical qualities of iron plates** vary greatly, for they depend not only on the quantity and nature of the impurities (which vary in each plate), but on their distribution and on the texture of the iron, the last two features depending on the nature and amount of the manipulation the plate receives during manufacture. It follows, therefore, that different plates may give widely different results under test, as regards both strength and ductility; it is found, for instance, that test pieces cut even from different parts of the same plate may possess different mechanical qualities. Tensile strength is no criterion of the goodness of iron, for an inferior material, having a large percentage of impurities, is often stronger than a high-class one. Thus, while a soft, pure, Swedish iron may have a tensile strength of only 19 tons per square inch, a hard, impure material, resembling puddled steel in its general characteristics, may have a strength approaching 30 tons; but whereas the former will stretch over 30 per cent. of its length (in 8 inches), and bend through large angles before breaking, the latter will not stretch at all, and will crack almost on the attempt to bend it, the fracture showing an irregular, crystalline structure. The purity and good quality of iron is best ascertained by ductility, or cold bend tests. The best bar iron, such as is used for rivets, will bend double before cracking, its fracture (when broken) showing a uniform silky texture. Compared with this material, ordinary ship iron is hard and brittle; that formerly used by the Admiralty, and which was very good of its kind, was considered satisfactory if it stood the very moderate cold bend tests illustrated in Figs. 21, 23, and 25, Plate 99; the requirements of Lloyd's Register for the plates of iron masts being shown in Figs. 20, 22, and 24. Even when hot, a $\frac{1}{2}$-inch plate of ordinary iron will not bend crosswise (*i.e.* parallel with the grain) through as much as 90 degrees, and, consequently, in the case of iron garboard plates, it was necessary to secure a special quality of iron, the plates being rolled as much as possible crosswise as well as longitudinally, so as to distribute the fibre in either direction. Iron bars, when in process of manufacture, are, of course, only

rolled longitudinally, and as the fibre, in consequence, lies entirely in this direction, the mechanical qualities under test are particularly poor; in the days of iron shipbuilding, the frequent failure of the frames, etc., during the bevelling process was a source of much trouble.

Art. 549. Mild steel may be defined as pure, homogeneous iron, with rather less than 1 per cent. of certain foreign elements (see the analysis on the opposite page). In process of manufacture, it is a liquid mass, which, when of the proper composition, is poured into moulds to form the ingots from which the plates and bars are subsequently rolled. The foreign elements differ from the impurities found in iron, in that they are definite in amount, and are so intimately mixed that the whole forms a perfectly dense, homogeneous alloy. The slag and light impurities, which, in the case of iron, become mixed up with it in the puddling furnace (the heat of a puddling furnace is insufficient to liquify malleable iron), are entirely absent in steel, for though present in the furnace, they float harmlessly on the top of the molten metal. Owing to the perfect homogeneousness of mild steel, its physical structure is comparatively little affected by mechanical treatment, for although this causes variations in the molecular arrangement, it gives rise to no definite fibre, and, consequently, the physical qualities under test are practically the same in whatever direction the stress is applied.

In the case of iron, the extent of the **manipulation or "work"** it receives during the hammering and rolling process has a far greater influence on the mechanical qualities than its composition as regards impurities, for as the latter are in great part merely entangled in the mass, variations in their amount may have little effect on its behaviour under stress. With steel, on the other hand, as the impurities form an alloy, they have a commanding influence on the molecular structure, and, consequently, a very small variation in their proportion may have a most commanding effect on the strength and other mechanical qualities.[1] In steel made by the "open-hearth" process, the more important foreign elements are almost perfectly under control, so that not only is great uniformity in composition readily obtained, but, by suitably varying their proportions, widely different mechanical qualities. In the early days of mild steel the foreign elements were not thoroughly under control, and, consequently, the qualities of strength and mildness were matters of great uncertainty. "Mild steel" was so called to distinguish it from the hard, brittle material which until then was alone known as steel. The term "mild" is generally used in contradistinction to "hard," and signifies the qualities of softness, ductility, weldability, and insusceptibility to injury by heating and cooling and by punching and shearing operations.

As is, of course, well known, it is the element **carbon** which transforms pure iron into steel, and, within a certain limit, the greater its proportion the harder and stronger the steel. From the analysis given on the next page it will be observed that carbon is also present in malleable iron, but as it exists here mainly as an entangled impurity, it does not confer hardness and strength. The *softest mild steel* differs little from a chemically pure iron; it contains less than one-tenth per cent. of carbon, its strength is about 20 tons per square inch, and it stretches more than 30 per cent. of its length before breaking. In passing from this material to a hard, *high-carbon steel*, the qualities of mildness and ductility gradually disappear. The *hardest steel*—such as is used for razors, etc.—contains about 1·4 per cent. of carbon, its tensile strength is about 100 tons per

[1] The mechanical qualities of a metal may undergo a complete change by alloy with another, and even though the latter be present as a very small percentage.

square inch, it cannot be welded, and, of course, it is extremely brittle. Between these two extremes (of a very mild, low-carbon steel, and a very hard, high-carbon one) steel of any required strength may be readily produced, the ductility and general mildness, however, being in inverse proportion to the strength.

Elements.	Analysis of mild steel.[1]	Analysis of malleable iron.[2]
Iron	99·185	99·090
Carbon	0·180	0·111
Silica	trace	0·088
Sulphur ...	0·045	0·094
Phosphorus ...	0·045	0·117
Manganese ...	0·500	0·000
Copper	0·045	0·000
Slag, etc. ...	0·000	0·500
	100·000	100·000

Art. 550. In considering what **particular "grade" of steel**, as regards strength and mildness, is the **most suitable for ships' hulls**, it is evident that, as the two qualities are opposed, a suitable compromise must be made between them. In 1875, when mild steel of almost any specified strength first became available, the quality of mildness was deemed so important that, to obtain it, the comparatively low strength limits of 26 tons[3] minimum and 30 tons maximum were adopted (both by the Admiralty and Lloyd's Register); soon, however, they were raised to 27 and 31 tons, and now they stand at 28 and 32. The great value set upon mildness, and the consequent inclination to adopt a comparatively weak material, arose from the circumstance that the mild steel produced prior to 1875, while possessing ample strength, was often seriously deficient in mildness and general reliability. The material employed in France was apparently very treacherous stuff.[4] By the action of the punch or shears it often lost as much as 50 per cent. of its strength, and, as bending or hammering treatment was often followed by spontaneous rupture, it was found necessary to anneal every part after manipulation, whether it had been worked hot or cold. As it was particularly susceptible to injury when worked hot, bending operations, wherever practicable, were done cold, by hydraulic machinery; and as the shock of hammer blows was found to be injurious, gradually applied pressures were substituted, the workmen being forbidden the use of hammers. In riveting operations the use of the drift was prohibited, unfair holes being corrected by rat-tail files.

Art. 551. Steel was not adopted as a substitute for iron merely that vessels built of it might be stronger, but in order that the smaller scantlings warranted by its greater strength and better mechanical qualities might, by reducing the structural weight, increase their carrying power and commercial efficiency. An increase in commercial efficiency was, of course, essential, as compensation for the greater outlay, for in those days steel cost about twice as much as iron. The decision as to how much the scantlings might be reduced rested principally with the classification societies, who concluded that a diminution of one-fifth was safely permissible, experience

[1] Riley.
[2] Thurston.
[3] In the following, the strength of material is stated in tons *per square inch*.
[4] M. J. Barba, "*Account of the use of steel in Naval Construction*."

indicating that, as regards strength and stiffness, steel and iron structures were then fairly equal.

Now, a steel plate of 30 tons tensile strength is 50 per cent. stronger than an iron one of 20, and, accordingly, as regards resistance of tensile stress, a reduction in thickness of one-third would still leave it equally capable. But the plates and bars of a vessel's hull are not liable only to tensile stress, but also to compressive, shearing, and bending stresses, in resisting which steel is not so markedly superior to iron; and, moreover, while a reduction in thickness does not affect the tensile strength of a plate or bar (per square inch), it diminishes its resistance (per square inch) to compressive and bending stresses. Thus, while the resistance offered by, say, the shell plating to the bending effect of water pressure (or pressures due to grounding) varies in direct proportion to its tensile and compressive strength, it also varies as the cube of the thickness; and, consequently, a reduction of, say, one-third in the thickness would be accompanied by about three times the deflection under the same bending pressure; it follows, therefore, that to maintain the stiffness unreduced, a steel plate two-thirds the thickness of an iron one would require to be three times as strong instead of only one and a half times.[1] It is evident, therefore, that the important quality of stiffness does not permit of a reduction in scantlings proportionate to the tensile strength of the material. Another reason why the apparently small reduction of one-fifth should be adopted, is the desirability of providing against the greater loss of strength which steel, compared with iron, suffers by the action of the punch (Art. 286).

Art. 552. The use of **steel for classed vessels**, with a reduction in scantlings of 20 per cent., was sanctioned by Lloyd's Register, subject to its being carefully and **systematically tested**, to make sure that it possessed the strength on which the reduction in scantlings was based, and that it was mild and reliable. Tests were deemed particularly necessary, for although the mild steel of that period was superior to iron (tests of which were not required), it exhibited, on occasion, defects so unfamiliar and startling that considerable doubts prevailed as to the propriety of employing it for ships' hulls. For although iron, when subjected to but small manipulation, might crack, with little evidence of ductility, the phenomenon was familiar and not unexpected, whereas in the case of steel, although so ductile as to bend like copper, it sometimes cracked of its own accord, or as an immediate result of some simple manipulation; and by the action of the punch it sometimes lost almost half its strength, and became quite brittle. The desirability of testing ship iron, though often urged, was impracticable, for as no two iron plates are alike, it would have been necessary to test each one. With steel, on the other hand, efficient testing is a simple matter, for as a large number of plates and bars are made from one molten mass or "*charge*," tests made from one or two of them may serve for all. The tests required by Lloyd's Register were, at the first, carried out in the shipyard, one plate in every fifty or so being chosen at random, and a part cut off to make the necessary test pieces. This plan, however, was found to be unsatisfactory, for as it was possible for a whole charge to escape testing, bad material was not always discovered; then the cutting of test pieces from the plates spoiled them for their intended purpose, and delays occurred in replacing them. Further, efficient testing machines were not found in every shipyard, and the manufacturers were not always willing to replace material condemned by tests not made

[1] While the stiffness varies as the cube of the thickness, the flexibility varies inversely as the cube, so that a plate two-thirds the thickness of another will deflect $(\frac{3}{2})^3$, or rather more than three times as much.

in their presence. In view of these objections, therefore, the testing of the steel was intrusted to the manufacturers, the operations being carried out in the presence of Lloyd's surveyors.

As the **testing of the raw material** is an important operation, it will be well to notice how it is carried out, and other matters in connection with the mechanical qualities of steel generally. Lloyd's requirements are as follows:—

Tensile strength:—This must not be less than 28, nor more than 32 tons per square inch; excepting plates which are to be flanged cold, where a minimum strength of 26 tons is permitted, and angle and other bars, which may have a maximum strength of 33 tons.

Ductility:—Tensile test pieces, when pulled asunder, must stretch not less than 16 or 20 per cent. in a length of 8 inches, the smaller percentage in the case of material thinner than $\frac{8}{20}$ inch, and the larger for material of that thickness and above. Further, the ductility must be such that test pieces shall bend double when cold, also, after being heated to a cherry-red and quenched in water not hotter than 82 degrees Fahr., the inner radius of the bend not being greater than one and a half times the thickness of the material (see Fig. 26, Plate 99). The last two tests are often referred to as "forge tests," the first being termed a "*cold bend test*," and the other a "*temper bend test*." It may be observed that good steel will usually stand much more severe bending treatment than that just described; a severe bend test is shown in Fig. 27, Plate 99, and tests of angle bars in Fig. 19.

The foregoing tests do not, of course, represent actual working requirements, but simply a standard of excellence, as regards the combination of strength and ductility, readily attained in carefully made steel. They may be regarded as a mechanical analysis of the nature of the steel, failure to satisfy which signifies a deficiency in some important characteristic. They are useful not only in proving the steel capable of resisting the stresses to which it is liable when forming part of a vessel's hull, but in withstanding without injury—latent or apparent—the manipulation received in the shipyard. In the case of angle and other bars, a maximum strength limit of 33 tons in place of 32 is permitted, because the rolling to which they are subjected tends to raise the strength, and as the function of bars is usually to stiffen and support plated surfaces, stiffness and strength are here particularly advantageous qualities. In the case of plates which are subjected to the severe treatment of cold flanging, a minimum strength of 26 tons in place of 28 is allowed, in order to permit of sufficient ductility. The British Corporation adopt, generally, the same strength limits as Lloyd's Register; but in the case of cold-flanged plates, while they permit a 25 ton lower limit, they do not allow a greater strength than 29 tons, which ensures ample ductility, and that the plate shall not be injured by the flanging treatment.

The usefulness of an **upper strength limit** may not at first sight be apparent, for it may be argued that so long as the steel satisfies the ductility tests, the fact of its strength being considerably above the usual maximum would be rather advantageous than otherwise. In practice, however, it is found that the quality of mildness varies inversely as the strength, and although great strength is in itself advantageous (in that it provides a high factor of safety), it is not so if accompanied by a loss of other useful qualities. Thus, the stronger the steel the greater is the injury it suffers from punching and shearing operations. The efficiency of a riveted structure may, indeed, be diminished rather than increased by irregular variations in the strength and stiffness of its component parts, for, when exposed to

severe stress, the more ready yielding of the weak may throw undue stress on the strong, tending to break them or cause local straining of the riveting.

When a **tensile test piece** is subjected to an increasing stress, the resistance it offers passes through two phases. The first prevails until the stress is rather more than half the breaking strength; up to this point the **elongation** is hardly perceptible (it equals about $\frac{1}{700}$ of the length), and when the stress is removed the test piece springs back to its original length, *i.e.* the **elasticity** up to this point is perfect, the steel suffering no permanent deformation or injury. On entering the second phase, the test piece begins to draw out visibly and *permanently*, the elongation increasing with each addition of load (but not regularly or proportionately), until finally, when fracture occurs, the test piece may be 25 per cent. longer than originally (see Figs. 9 to 12, Plate 99). The maximum strength in the first phase is known as the "**elastic limit**;" it measures the useful strength of the steel, for if any part of a structure were subjected to a greater stress, the resulting permanent stretch might be fatal to the integrity of the whole. But although the elastic limit is thus more important than the ultimate strength, it is, nevertheless, almost ignored in ordinary testing procedure; this is because of the difficulty of ascertaining it, *i.e.* of noting at what precise stress the test piece begins to stretch permanently, and also because it is not a fixed quantity, but varies according to the mechanical treatment to which the steel has previously been subjected. With ordinary mild steel it usually lies between 0·5 and 0·55 of the breaking load. The stronger the steel, the more nearly does it approach the breaking strength; in high-carbon tool steel, for instance, in which the breaking strength may be as high as 100 tons per square inch, the two are practically the same, there being no permanent stretch before fracture; but although such material might, therefore, stand a very high stress without injury, the fact of its having little or no ductility, and of its consequent liability to snap short under sudden stress, makes it quite unsuitable for structural purposes.

What is known as the "**factor of safety**" is the excess of the breaking strength over the working stress. Steam boilers and land structures, such as bridges, etc., are usually designed of such proportions as will give them—by calculation—an ultimate strength from four to six times the greatest stress ever likely to be experienced. When the load is a "*live load*," *i.e.* one whose application is accompanied by shock or vibration, a larger factor of safety is provided than when it is a "*dead load*," *i.e.* one whose application is permanent or gradually applied. In the case of some very long vessels the stress experienced by certain parts of the hull may, under certain conditions, approach an intensity of 10 tons per square inch, which, with 30-ton steel, would give a factor of safety of only 3; and if the elastic limit were, say, 0·55 of the breaking strength, or 16½ tons, there would only be the small margin of 6½ tons against permanent straining of the hull. A factor of safety of 3 is less than would be considered prudent for land structures, but even in the few vessels whose proportions are such as to make so high a stress possible, the conditions necessary to bring it about rarely occur.

For torpedo boats, in which a very light, yet strong hull is of the utmost importance, it becomes very advantageous to use an exceptionally strong steel, so that the scantlings may be correspondingly small. The material now generally used in such vessels, for the shell plating and other important longitudinal parts, has a tensile strength varying from 37 to 43 tons per square inch. It is known as "high-tensile," or "high-carbon" steel, the percentage of carbon being about 0·40, or rather more than twice that usual in

ordinary mild steel. Although so strong, its ductility is very good; the elongation is about 15 per cent. in 8 inches, and samples, having filed edges, may be bent double with the usual radius of one and a half times the thickness. As steel of this character is greatly damaged by the action of the punch, it is found advisable not to punch any holes, but to drill them all (Art. 286).

Art. 553. The following is the **procedure** in vogue at the steel works **in testing** the various plates and bars. From each liquid *charge* or *cast* of steel, of ordinary size, about 10 **ingots** are obtained, and from each ingot about 10 plates, or in all, say, 100 fair-size plates. Now, as all these plates are similar in chemical composition (for they emanate from the one liquid mass), their mechanical qualities must be much the same, and, accordingly, tests made from any one of them may be sufficient to prove the quality of them all. In practice, while only one or two tensile tests are made from each charge (if the material varies in thickness by as much as $\frac{3}{20}$ inch, an additional test is made for each variation), a temper bend or cold bend test (an equal number of each, in each charge) is made from every plate or bar. In large steel works there are numerous melting furnaces, each of which is known by an alphabetical letter; and the various charges turned out from each one are numbered consecutively, as also the plates or bars rolled from each charge. For purposes of identification, every plate is stamped with the furnace letter and two numbers; thus "2, 99, A" means the second plate rolled from the 99th charge of A furnace; and as each plate is cut to the ordered dimensions, three or four shearings are stamped precisely as it is stamped, and are put carefully aside, so that the surveyor whose duty it is to test the steel may select at any time test pieces from any plate of any charge; and he may also select and stamp the required shearings himself, before they are removed from the plates.

The shearings selected for tensile test are cut to the form shown in Fig. 9, Plate 99, several being prepared simultaneously in a special machine. The middle part is made parallel and narrower than the ends, so that the elongation and fracture may occur here. The edges are finished quite smooth, because any roughness or irregularity would form a starting point for fracture, and as the stretching would be localized at this point, the strength and ductility would both be small, *i.e.* the test, as a representative one, would be vitiated. The dimensions of the test piece are unimportant, so long as the narrow part is at least 8 inches long.

Art. 554. A **testing machine** is shown diagrammatically in Fig. 18, Plate 99. It is practically a steel-yard weighing machine, with the addition of a hydraulic ram to give continuous compensation for the stretching of the test piece. The "jockey weight" travels along the long arm of the beam or lever, on which there is a graduated scale of tons, and its position upon it indicates the load at the end of the small arm, or, in other words, the pull on the test piece. The upper end of the test piece is connected to the extremity of the short arm of the lever, and the lower one to the hydraulic ram; they are held each by a pair of steel wedges having serrated faces, which grip them the tighter, the greater the pull.

The action of the machine, in breaking a test piece, may be described as follows: first the weight is run out until the lever begins to fall, which shows, of course, that the test piece has begun to stretch. In order to indicate accurately, the lever should not depart from the horizontal, and, accordingly, stops are provided to limit its movement, as shown. Owing, now, to the continued stretch of the test piece, the beam would soon pass the horizontal and rest on the lower stop, when, of course, no further stress would fall on the test piece, and it is to counteract this that the

lower end of the test piece is connected to a hydraulic ram, for as this may be made to descend throughout the operation, precisely as the test piece stretches, the lever need not—if the jockey weight is properly manipulated—move at all, however variable the stress or great the stretch. So long as the beam is balanced horizontally, the mere movement of the ram does not, of course, affect the stress on the test piece. When the latter breaks, the lever falls on the lower stop, and the longitudinal position of the weight upon it, at that moment, indicates the breaking stress, which, of course, is converted into tons per square inch by dividing it by the original area of the test piece.

Art. 555. Sketches of a **test piece** before and during the test, and finally when broken, are shown in Figs. 9 to 12, Plate 99. And the curve shown in Fig. 8 exhibits conveniently the **stress** and corresponding **stretch** of a test piece; it will be observed from this that, until the elastic limit (16 tons) is attained, there is practically no stretch; above this, however, it becomes very noticeable, the total stretch increasing with each addition of load. As will be seen from Fig. 10, the stretch of a test piece is fairly uniform throughout its length until the breaking stress is approached; it then becomes irregular, some parts drawing out more than others, and, when about to break, a sudden local extension occurs (Fig. 11), the breadth and thickness of the test piece diminishing quickly at this place, so that the steel appears to flow like some plastic substance, and, finally, rupture occurs (Fig. 12), usually with a loud clang. It should be observed that the *final* rapid stretch and local reduction in sectional area occurs without any increase in load.

As the sectional area of a test piece diminishes with the stretching (the reduction in sectional area of a broken test piece may be as great as 60 per cent.), it is evident that the steel must acquire strength by the mere process of drawing out, for while, when of its original sectional area, it elongates under a stress of about 16 tons, it requires, as it stretches, a greater and greater stress to continue the elongation. But although the steel composing a stretched test piece is thus stronger than originally (*i.e.* as regards elastic limit or its resistance to permanent stretch), it is in a strained and unnatural condition, and may be capable of little further stretching. If, however, such a stretched test piece is *annealed*, it will at once regain its original mechanical qualities; and if the annealed test piece is machined parallel and retested, it will again begin to elongate as formerly, at about 16 tons per square inch, and continue to stretch exactly as before. This procedure of alternately stretching and annealing may be continued almost indefinitely, the test piece becoming many times longer than originally; the operation, of course, is simply "wire drawing," and, as is well known, the strength of a steel or iron wire may greatly exceed that of the undrawn metal. The interesting fact may be noticed here that the mechanical properties of a strained test piece undergo alteration by the mere lapse of time; thus, if a test piece, when strained, say, to 20 tons, is removed from the machine, its elastic limit, in its now strained condition, will, of course, be 20 tons, for permanent stretching will only begin again when it is subjected to this stress; if, however, it is put aside for a day or two and again tested, it will not begin to stretch until the stress applied is considerably greater than 20 tons, showing that it has acquired a higher elastic limit. Also, if a test piece, when showing the marked local stretch and reduction of sectional area which precedes fracture (Fig. 11, Plate 99), is relieved of stress for a day or two, it is not uncommon, when it is afterwards pulled asunder, for the fracture to occur at a higher stress, and not at the greatly reduced place where formerly it was about to occur.

It will be observed from the test piece illustrated in Fig. 11, Plate 99, that the **stretch is not uniform throughout the length**, for while the 1-inch spaces—drawn across it—have increased in way of the break to about $1\frac{1}{2}$ inches, or by 50 per cent., those elsewhere have only increased to about $1\frac{1}{4}$ inches, or only half as much. It is evident, therefore, that the elongation of a test piece, when stated as a percentage of its length, depends on the distance over which it is measured. Lloyd's rules specify a **distance of 8 inches**. To ascertain the elongation of a test piece, centre-punch dabs are made upon it 8 inches apart, and after it is broken the two pieces are placed together and the increased distance between the dabs noted.

The **fracture** of good steel has a uniform **silky** appearance, of a dark silvery grey colour, perfectly free from crystals or metallic lustre. In thick plates, however, say, over 1 inch, the fracture is seldom uniformly silky; it is so near the margins, but at the centre it has often a more or less crumby appearance, due, no doubt, to difference in the extension of the material at the sides and centre at the moment of fracture.

Art. 556. Plates and bars, though made from the same charge, are not always identical in strength and ductility; the variation is usually small, not greater than 2 or 3 tons in strength, nor 4 or 5 per cent. in elongation. This may be due either to variations in the molecular arrangement of the steel through differences in the rolling procedure, or to slight differences in its composition through concentration of the foreign elements as the molten metal cools and solidifies in the ingot moulds.

Steel gains in strength as a result of work done upon it in a cold or semi-cold state, *i.e.* of any mechanical manipulation which disturbs its molecular arrangement; but the gain in strength is usually accompanied by a loss of ductility and mildness. As already seen, it gains strength when stretched in the testing machine; and if a test piece is elongated by hammering or rolling, its strength may be increased very considerably, its ductility, however, being correspondingly reduced. It is important to notice that all such artificial variations in strength and ductility are dissipated by annealing; that is to say, heating to a bright red, followed by slow cooling, dissipates the abnormal molecular arrangement induced by cold working.

In the manufacture of plates, the rolling process is sometimes continued after they have cooled below a red heat; this is termed "**cold rolling**," the result of which is an increase in the strength of the plates. **Thick plates** are rarely subjected to cold rolling, for, being thick, they part slowly with their heat, and the rolling process is of short duration. **Thin plates**, on the other hand, part quickly with their heat, and as they take longer to roll, they are often comparatively cold during the last few passes; and, further, as they are thin, the pressure of the rolls and its disturbing effect on the molecular structure is more searching. In the case of sheet steel, it is usual to dissipate the hardening effect of the unavoidable cold rolling by subsequent annealing; a number of sheets being heated, and then piled on top of one another so as to retard the cooling. In the case of sheet iron, advantage is taken of the strengthening effect of cold rolling, the process being continued when the sheets are quite cold; and this has the further advantage of producing a more perfect fibre and a smooth, well-finished surface. It follows from the above that thin and thick plates, even though identical in composition, may give different results under test. Thus a $\frac{1}{4}$-inch plate is usually 1 or 2 tons stronger than a $\frac{3}{4}$-inch one, the elongation, however, may be 3 or 4 per cent. less. It is to meet this that Lloyd's rules allow a smaller elongation in thin plates than in thick (16 versus 20 per cent.); and it is also because of this that they require

additional tensile tests when material, rolled from the same charge, varies in thickness by as much as $\frac{3}{16}$ inch.

In the case of iron, the rolling process, whether hot or cold, produces a well-marked **fibre.** This improves the strength and ductility, but only in the direction of the fibre, and in order, therefore, to distribute the beneficial effect, the plates are rolled, as much as possible, crosswise as well as longitudinally. With steel, the rolling does not produce any fibre, but it induces a certain **longitudinal arrangement of the molecules,** the effect of which is to make the ductility of transverse test pieces rather less than that of longitudinal ones. With thick plates the effect is rarely observed, for as they are hot when finished, the natural annealing process dissipates whatever abnormal molecular arrangement may have been induced by the rolling; nor is it usually observed in bars, for a similar reason. With thin plates, on the other hand, though the strength of a cross test piece may be no less than that of a longitudinal one, its ductility is often considerably less. Further, the behaviour of a cross test piece at the moment of fracture is somewhat different from that of a longitudinal one, for it does not contract and flow so markedly at the point of fracture, nor does it break with so loud a noise, and while the fracture of the latter is often of the ideal "cup" shape (Fig. 13, Plate 99), it is never so in cross tests.

As the fluid steel cools and solidifies in the ingot mould, the **carbon and impurities,** until then uniformly distributed, tend to **condense towards the centre and top of the mass,** and the more so the slower the cooling. The percentage of carbon in the lower part of the ingot is always considerably smaller than at the top, and this is taken advantage of where a specially mild, low-carbon steel is required. Thus, in thin plates, the strengthening and hardening effect of the cold rolling to which they are usually subjected may be provided against by making them from the lower part of the ingot. And similarly in the case of plates which require to be flanged, and in which ductility is particularly important. Very commonly a charge of soft steel is specially made for boiler plates (whose strength need only be 26 or 27 tons, according to its location), but, failing this, the lower parts of ordinary ingots are used. Thick plates, say over 1 inch, receive little manipulation of a cold-working or strength-giving nature, and as, owing to their slow cooling, they undergo a natural process of annealing, their tensile strength is low compared with thinner ones; for such, therefore, it is necessary to use a steel having rather a high percentage of carbon, say 22 per cent. in place of the more usual 17.

Art. 557. The ductility of the steel is tested not only by tensile tests, but by **cold and temper bend tests.** In proving ductility, bend tests are often more conclusive than tensile, for the extension of the material on the outer surface of the bend may exceed 40 per cent., or double the extension required under tension. It is important to note that bend test pieces are rough, *unplaned shearings*, for the character of the edge has a commanding influence on their behaviour under test. As described in Art. 286, the action of the shears tends to harden or reduce the ductility of the steel immediately contiguous to the edge, so that when subjected to severe stress of any kind the premature cracking of this hardened layer is at once followed by complete failure. A tensile test piece, having a sheared edge, usually snaps with little or no elongation, and at a low stress; and in bend tests there is also a marked tendency for cracks to develop at the edges, and, of course, when once started, they run across. Bad steel is injured to an amazing extent by shearing and punching; test pieces of such material, having rough edges, may sometimes be broken with a single blow, but if the edges are planed, or if the test pieces are annealed after shearing,

they will often bend double without sign of fracture. Good mild steel suffers only slightly from the action of the shears or punch. A special machine is usually employed for making bend tests, otherwise they may be bent by hammer blows, which procedure, however, on account of the concussive effect, is more severe on the steel. It is usual so to bend the test pieces that the "rag," or "fin," raised by the shear knife is on the inner surface of the bend, where it suffers compression; for if on the outer surface, it is exposed to the maximum tensile stress, and, in stretching, is very apt to start a crack. In view of this, Lloyd's rules permit, in the case of cold-bend tests, of the fin being removed; as also in the case of temper bends, if $\frac{1}{2}$ inch thick and above. And, in the case of boiler plates, when the thickness is 1 inch or more, the edges of cold-bend test pieces may be planed.

Art. 558. Cold bend tests are useful in proving the capabilities of the steel for the operation of **cold flanging.** When cold-flanging machines were first introduced, many of the plates failed by cracking along the knuckle, and to ensure sufficient ductility Lloyd's rules now require a cold bend test to be made from each plate intended to be flanged cold. The cracking of a plate under cold-flanging treatment would appear to show very inferior ductility, or even brittleness, for the angle of the bend is only 90 degrees, and the radius of knuckle is seldom so small as the standard of one and a half times the thickness required in a bend test; but this is disproved by the fact that cold bend tests made from cracked plates may give satisfactory results, bending even double without sign of fracture. This is explained by the fact that, compared with the bending of a small test piece, the flanging of a plate is more severe on the steel. In the case of a narrow test piece, the material on its outer surface, by flowing inwards from the edges (Fig. 27, Plate 99), is able to minimize the longitudinal stretch required of it (the same principle is observed in a tensile test piece, where the marked lateral contraction at the point of fracture permits of greater elongation at this point); and, similarly, the material on the inner surface of the bend, by an outward flow towards the edges, is able to minimize the longitudinal compression or thickening effect required of it. In a flanged plate, on the other hand, only the material contiguous to the edge finds relief by lateral flow. Another circumstance which makes the flanging of a plate a more severe trial than a mere bend test, is that the plate is bent over a sharp edge, the pressure of which may interfere with the natural flow of the steel. In the first flanging machines, the plates were gripped above and below in the same line, and in consequence of the sharp nip and interference with the flow of the steel at this point, few plates withstood the treatment. This is now corrected (Fig. 4, Plate 83), by placing the lower clamping piece (P) slightly within the upper (more or less according as the plate is thick or thin), which permits of free and more widespread straining of the steel, and results in an easier and more symmetrical knuckle.

Art. 559. Temper bend tests differ from cold bend tests, in that the test pieces are first heated and cooled in water. Their purpose is to prove the general mildness of the steel. As is well known, sudden cooling tempers, or hardens high-carbon steel, such as is used for tools, *i.e.* it makes it stronger but less ductile, the degree of hardness depending on the intensity of the heat and the suddenness of the cooling. The milder the steel the less is it affected; in ordinary ship steel the hardening effect due to quenching from the "low cherry-red" specified in Lloyd's rules is only such as to increase the strength by about 2 tons, and lower the elongation by about 5 per cent. If quenched at a yellow heat, the strength may

be increased by as much as 8 tons, and the elongation diminished by perhaps 10 per cent.

Although the slight loss of ductility caused by the tempering process is unfavourable to successful bending, it favours it by dissipating the hardness induced by the shearing or cold rolling; and the latter effect is far more important than the former, for while cold bends (with rough sheared edges) often fail and can seldom be bent with a much smaller radius than one and a half times the thickness, temper bends rarely fail, and if not too thick can usually be bent quite close, under the steam hammer, as shown in Fig. 27, Plate 99. The effect of the tempering process is well shown by the difference in the mode of fracture of a cold and a temper bend, for while in the former the crack always starts at an edge, in the latter it may begin between the edges. It is clear, therefore, that with good mild steel, temper bends are really not so severe a test as cold bends, *i.e.*, of course, when both have rough sheared edges. As noticed in Art. 566, the alloy *manganese*—always added to mild steel—strengthens it in much the same way as carbon, but with this important difference, that, while carbon increases the loss of ductility caused by tempering, manganese tends rather to reduce it. Its use, therefore, permits of a smaller percentage of carbon, an important matter in obtaining satisfactory results under temper tests.

Art. 560. Steel is not equally ductile at all temperatures; when cold it is tough and malleable, and also when red hot, but between these two temperatures its toughness almost entirely forsakes it, so that it is aptly described by the word "rotten."[1] This critical condition is known as a "*blue*" or "*black heat;*" it ranges from about 400 to 650 degrees Fahr., these being the temperatures which cause a display of temper colours. It may be noticed that a temperature of 430 degrees Fahr. is the melting point of tin, 630 is that of lead and is also the temperature of boiling tallow, and that the temperatures corresponding to a dull red, a white heat, and a melting heat (of steel) are, respectively, about 1000, 2200, and 2700 degrees Fahr.

The **loss of ductility at a blue heat** is well shown by the following experiment:[2] of 48 test strips cut from a steel plate, 24 were bent double, when cold, round a bar whose diameter was twice their thickness, and not one of them cracked; the remaining 24 were similarly treated, but when they were at a blue heat, obtained by immersion in boiling tallow, and every one of them cracked, long before the two parts when bent over became parallel. Other test experiments give, as a general result, that while strips when cold will bend backwards and forwards through 40 degrees, with about a 2-inch radius, from twenty to twenty-five times without cracking, they will only bend some two or three times when at a blue heat. It should be observed that steel at a blue heat is not exactly brittle, for it does not snap short with a crystalline fracture.

Iron also loses ductility when at a blue heat, and to much the same extent as steel; thus, while test strips from a $\frac{3}{16}$-inch Lowmoor-iron plate were bent cold about twenty times through 40 degrees, they broke when blue hot at the third bend. Unless very thin, iron plates always show poor ductility under bend test; a strip from a $\frac{3}{8}$-inch Lowmoor plate,

[1] An account of various experiments on the effect of temperature on the mechanical qualities of mild steel, and other matters in this connection, will be found in a paper (and the discussion thereon) by Mr. Stromeyer, *Trans. Institution of Civil Engineers*, 1885; and in another by Mr. Nodder, *Trans. North-East Coast Institution of Engineers and Shipbuilders*, 1893-4.

[2] See Mr. Stromeyer's paper already cited.

for instance, will bend, when cold, once through 40 degrees, but will probably crack on being straightened; at a blue heat, however, it will not bend so much as 40 degrees, but will probably crack at about 25, or if struck a sharp blow it will fracture at once, hardly bending at all.

As regards the **effect of a blue heat on the tensile strength and elongation** of steel, numerous experiments show that at a temperature of about 600 degrees Fahr., while the former is raised from 12 to 24 per cent., the latter is diminished by from 50 to 60 per cent. It is important to notice, however, that although the ultimate strength is increased, *the elastic limit is lowered*, and that by as much as 40 to 50 per cent. Thus, while ordinary cold steel will begin to draw out permanently, or yield, at a stress of from 16 to 17 tons per square inch, it will, when blue-hot, begin to yield at 9 or 10 tons, and this, as noticed in the following, is an important matter as regards the manipulation of steel in shipbuilding and repair work.

Although, when steel is cold, it is tougher and can withstand greater deformation than **when blue hot,** its smaller elastic limit, or greater readiness to yield when in the latter condition, makes it **more amenable to shaping or bending treatment.** For this reason, when a plate or a bar requires to be bent locally, and the forces at disposal are insufficient or difficult of application, it is a common practice first to heat slightly the part, or, as it is usually expressed, "take the chill off." This procedure is principally confined to repair work. Indents in the shell plating, for instance, may usually be faired in place without removing the plate, by drilling one or more holes in the depressed part, affixing a strong-back, as shown in Fig. 7, Plate 99, and, while heaving up the screw bolts, hammering the plate out from within. The operation may usually be done cold, but if the plate is thick, or the deformation considerable, the steel is first heated by applying the flame of a special blow lamp, or, if the part to be heated is large and massive, a fire may be made around it. The heat so obtained is less than a red heat, and in most cases is within the blue-hot range. In plates of awkward form, difficult to fit, such as the oxter or boss plates, heating in place is often resorted to. It should be observed that the reduction in the elastic limit is not confined to blue-hot temperatures, but takes place regularly from zero upwards.[1] It follows, therefore, that any increase in temperature, however small, must diminish the resistance of steel to bending treatment; and this is found to be the case, for when fairing slightly collapsed boiler furnaces, the mere warmth from boiling water or steam within the boiler is found to render the steel more amenable to bending treatment.

Art. 561. The foregoing describes the changes in the nature of the steel *when* blue hot; but there is another matter to notice, namely, the *permanent* damage done by working it at that temperature. When steel cools from a red heat, the passing phase of a blue heat does not, of course, affect its subsequent qualities; if, however, when in the blue-hot condition it is bent, hammered, stretched, or otherwise worked, the manipulation has the curious effect of rendering permanent the hardness and brittleness otherwise only prevailing during the blue heat. Thus, if two strips of steel are heated to redness and left alone to cool, both, when cold, will, of course, resume their original qualities; if, however, one of them *when passing through* the blue-hot phase is bent, say, through 40 degrees, and straightened, or if it is struck several blows with a hammer on an anvil, it

[1] Curves showing the variation of the elastic limit, and strength of different steels, at all temperatures from zero to a red heat, will be found in a paper by Mr. Morrison, *Trans. North-East Coast Institution of Engineers and Shipbuilders*, 1893.

will be *permanently injured;* for while the first will bend over twenty times through 40 degrees without cracking, the other will probably not bend even once, but will break with one sharp blow from a hammer, showing by its crystalline fracture that it has become brittle. Observe that when steel is broken *at* a blue heat it is rotten rather than brittle, for though it breaks short it does so with a silky fracture. The more extensive the mechanical work done at a blue heat, the more pronounced is the resulting permanent brittleness. It is important to notice, however, that all such deterioration is remedied by annealing. Iron also shows the above peculiarity, but not so markedly.

In conformity with the foregoing, it might be anticipated that the hardening or **damaging effect of the punch or shears** would be accentuated if the punching or shearing were done **at a blue heat**, and this is found to be the case. At the steel works, for instance, when work is hurried, thick plates, being slow in cooling, are often lifted by tongs and sheared when at a blue heat (a circumstance proclaimed by the temper colours on the shorn edge), and, as a result, the damage done to the steel contiguous to the edge—which, if the plate were shorn cold, would be comparatively slight—is pronounced and extensive. This is shown by tensile test pieces; for, to ensure good results, it is found necessary, in the case of thick plates sheared at a blue heat, to remove two or three times as much material from the edge of the test piece as is ordinarily sufficient. Having regard, therefore, to the possibility of thick ship plates being seriously injured by blue-hot shearing, it is well, in important ones, to remove the rough steel-work edge, preferably by planing. In the absence of such precaution the plate is not unlikely to crack under a comparatively small stress. In the case of the very thick plates used for boilers (up to $1\frac{5}{8}$ inches), the shears not only injure the steel, but so squeeze and destroy the edge as to necessitate the subsequent planing away of a considerable portion, and, accordingly, in some steel works such plates are not sheared, but are cut accurately to the finished dimensions in a special slotting machine.

It is evident, from the foregoing, that **the working of steel at a blue heat should be avoided** whenever practicable, not only on account of the greater liability of the steel to crack during the process, but because of the resulting permanent hardness and brittleness. In shipyard practice this is fairly well observed, the only work done to plates and bars at a blue heat being the comparatively small deformations made to correct the shape of parts previously bent when red hot, and which it would be inexpedient to re-heat as a whole. Final annealing would, of course, dissipate all the bad effects of such blue-hot working, but after slender plates and bars are bent to shape annealing is hardly practicable. In repair work, low heating is common, but here, again, the deformation, or work done at a blue heat, is usually so small as to leave ample ductility in the steel. Much, however, depends on the duty of the part dealt with; for while the injury done to ordinary shell plates may be inconsiderable, it might not be so in the case of the sheer strake or deck stringer plate amidships; as these are liable to severe stress, they should be as free as possible from any likelihood of brittleness, local or otherwise.

The extensive operation of **riveting** may be performed in great part when the rivets are blue hot, for, as they cool quickly, they are not red hot during all the time of the hammering (Art. 314). The **effect of hammering steel at a blue heat** is shown by the following experiment —one of many.[1] A tensile test piece of 27·2-ton steel, giving 26 per cent.

[1] See Mr. Nodder's paper, *Trans. North-East Coast Institution of Engineers and Shipbuilders*, 1893-4.

elongation in 8 inches, was struck, when at 400 degrees Fahr., sixty blows with a 9-lb. hammer on an anvil, and when afterwards subjected to tensile test its strength was found to be 32·3 tons, and its elongation 10 per cent.—a loss of ductility of 61 per cent. It follows, therefore, that the hammering of rivets at a blue heat, while increasing their strength, must greatly reduce their ductility. But although this would be a serious matter in the case of plates and bars, it is not so with rivets, for the efficiency of a rivet in clamping two parts together depends not on its ductility, but on its shearing strength, great ductility, or stretching power, being really detrimental to its resistance as a rigid connecting medium. It may be remarked that steel rivets are rarely found to fail in a manner indicating brittleness.

Art. 562. Spontaneous rupture may be defined as the cracking of a plate or bar of its own accord. Its immediate cause is the existence of internal stress, brought about usually by local heating and unequal or impeded contraction during cooling. The steels employed prior to the introduction of mild steel were particularly liable to spontaneous rupture; it was not uncommon, for instance, for shell plates to crack after they were riveted up, with a loud report.[1] With the early mild steel spontaneous ruptures were also not uncommon;[2] with the excellent mild steel of the present day, unless the treatment is improper, they are rarely observed. The edges of a spontaneous crack are sharp and square, and show practically no evidence of ductility, and yet, when test pieces are cut from the plate, close to the crack, the steel is usually found to have normal strength and ductility. The phenomenon has not yet been satisfactorily explained. A familiar instance of internal stress and rupture may be observed in channel or Z bars; when the web at one end is ripped up the middle, as is often done in way of the floors or turned beam knees, the two parts will spring asunder slightly (Fig. 21, Plate 95), and if the ripping is done gradually in a planing machine, they will spring asunder before the tool has quite traversed the web, the thin remaining part rupturing spontaneously under the opposing pulls of the two flanges. It should be observed that the process of annealing dissipates internal stresses, and, with them, any tendency to spontaneous rupture; and, accordingly, when the treatment of an important part is such as is likely to produce serious internal stress, the precautionary measure of annealing is always taken.

In steel vessels the plates and bars sometimes rupture spontaneously as a result of **damage by fire.** The heating red hot of the structural work, and the subsequent cooling, whether by water or naturally, causes great distortion of the various parts, the plating buckling and the bars bending and twisting; and as a result of the internal stress which such distortion denotes, the parts sometimes crack. The existence of internal stress is shown by the circumstance that, during the repairs, when the plates are relieved of the restraining influence of the various rivets, they become still more distorted. Not uncommonly some of the plates may crack during the process of removing the rivets, due to a local concentration of the stresses otherwise held in check or distributed by the rivets. In repairing important plates, damaged by fire, they should be annealed in order to dissipate all internal stresses. It is a curious thing that plates buckled by fire, and which appear to be permanently misshapen, recover practically their original shape and dimensions when flattened in the rolls or mangle; and this result is found to be best attained by rolling them

[1] See Mr. H. West's paper, "*Steel in the hands of the Naval Architect*," *Trans. of the Liverpool Engineering Society*, 1889.

[2] A remarkable instance of the kind is described in a paper by Mr. Parker, *Trans. Institution of Naval Architects*, 1881.

cold, the annealing being done subsequently. The mere heating and cooling of a plate shortens it slightly; in repair work, for instance, when a bent plate is removed, heated, faired, and replaced, its ends, if butted, do not fit so closely as they did, the discrepancy being greater, of course, with long plates. In view of this, the heating of damaged plates is usually avoided when practicable.

Art. 563. A large mass of steel, if **quickly cooled,** may, by the development within it of tensile and compressive stresses, suffer seriously in its power of resisting external forces. Large or irregular masses of metal, therefore, such as cast-steel stern-frames, rudders, anchors, etc., must always be annealed, this treatment dissipating the **internal stresses** brought about by cooling from a high temperature. The nature and origin of these stresses is well exemplified by the case of a large, cylindrical, steel ingot. When the liquid steel is run into the ingot mould, the surface metal is the first to cool and solidify, contracting all the time; subsequently, when it is fairly cold, and ceases to contract, it forms a hard and unyielding shell around the still liquid or very hot metal within, which, continuing to contract and to occupy less space, exerts a more and more intense inward pull on the hard crust. To this, of course, the latter cannot yield, for as it is circular or tube-like in section, it has enormous power of resistance; finally, therefore, as the metal towards the heart becomes smaller and yet is constrained, as it were, to occupy the same space, it rends asunder at places, causing flaws—*contraction flaws*—and fissures in the interior of the ingot. To avoid this, steel ingots are made of rectangular section, for their sides, being flat, are free to collapse and accommodate themselves to the internal shrinkage; the sides of a cold ingot are always slightly concave from this cause.

Just as a large mass may be ruptured internally by rapid cooling, so may it by **rapid heating.** In the case, for instance, of a cylindrical ingot suffering from internal stress due to rapid cooling; if, when it is quite cold, it is placed in a very hot furnace, the crust, already exerting an outward pull away from the heart, would at once expand under the heat and pull with increased force. In practice, steel castings in process of reheating sometimes crack in the furnace with a loud bell-like note, the stresses caused by the expansion, when added to those already existing, exceeding the endurance of the material. Castings of iron, when under the influence of internal stress, have been known to crack through mere exposure to the sun's rays.

What has just been seen regarding a massive ingot applies with even greater force to castings of irregular form and massiveness. In the case of cast-steel stern-frames, rudders, shaft brackets, etc., slender parts are often conjoined to bulky masses, and it is evident that, when subjected to external heat or cold, the former, by reason of their small mass and proportionately large heating or cooling surface, will be the first to heat or cool, and, by premature expansion or contraction, tend to sever their connection with the remainder, causing rupture, contraction flaws, or distortion.

Forgings, whether of scrap steel or iron, are also subject to internal stress, but as their temperature (when left alone to cool) is low compared with that of a casting, they contract less,[1] and as they are fibrous and less dense or homogeneous, internal stresses are better able to find relief. In the manufacture of forgings, when the numerous pieces of scrap are

[1] The shrinkage of cast steel in passing from the liquid to the cold, solid state is nearly $\frac{1}{4}$ inch to the foot, that of iron in cooling from a yellow heat is only about $\frac{1}{16}$ inch to the foot.

stamped and welded together, some, hotter than others or more directly affected by the hammer blows, may be squeezed into a state of tension, and others correspondingly into compression. Each different set may, therefore, exert a constant effort in keeping others in restraint, and, being thus in conflict with themselves, must evidently be less fit to resist superadded external forces. The weakening effect of imperfect co-operation (through internal stress) of the metal in a large forging may be forcibly illustrated by the imaginary case of a wire rope, in which, say, half of the wires are so much tauter than others as to pull them into little loops. It is evident that under such circumstances the strength of the rope would be reduced by half, for only the taut wires would resist the stress, and, of course, their failure would at once be followed by that of the remainder. Its strength, however, would really suffer a further reduction, from the circumstance that, as the taut wires, in pulling or compressing the others, would be in permanent tension, they would be less able to resist additional tensile forces from without.

Art. 564. As regards the **effect of annealing** in dissipating internal stresses, it is evident, when a mass of metal is heated to such an extent as to induce softness throughout, that the parts formerly under tension or compression must stretch or contract, and thus cease to re-act on one another. To ensure the final absence of all stress, the cooling should be slow; what is required is that every part of the casting, whether slender or massive, shall cool at the same rate, or, in other words, that the entire mass shall at each moment of the cooling be at practically the same temperature, for then, as all parts will contract at the same rate, there will be little or no tendency to pull or push one another. The heating should be slow, so that there may be no chance of fracture or the development of internal flaws through unequal expansion; compared with the cooling, however, the heating may be rapid. The period of cooling allowed in practice for steel castings may be anything up to about six days, a longer time being allowed for massive than for slender castings (Art. 570). An annealing furnace, or oven, is simply a large brick chamber, the temperature of which is regulated by admitting flaming gases. The casting to be annealed is carefully made up underneath with brickwork, so that, when softened by heat, it may not alter form; a bright red heat being attained, it is left to cool, in the slowly cooling furnace. Scrap forgings are not often annealed; when of steel, however, it is well that they should be.

In the thin plates and bars used in shipbuilding, the effect of external heat or cold passes at once from surface to centre, so that, in annealing them, neither the period of heating nor cooling need be protracted. Natural cooling in the open air, where free from local chilling effects, is all that is required; with thick plates, however, the cooling may be retarded, with advantage, by covering with ashes or sand. As already seen in the case of temper-bend test pieces (*i.e.* shearings from plates), sudden cooling in water has, as regards the dissipation of internal stresses, practically all the effect of annealing, but it also hardens, or tempers the steel, an effect which, of course, is quite different from that of annealing, the hardness so brought about being due to an alteration in the chemical and physical condition of the carbon, as an alloy of the iron.

Art. 565. Numerous experiments have been made to ascertain whether or not steel is injured by long-continued **exposure to heat, or oft-repeated heatings and coolings,** all of which appear to show that so long as the temperature does not exceed a yellow heat it is not injured.[1]

[1] See Mr. Nodder's paper, *Trans. North-East Coast Institution of Engineers and Shipbuilders*, 1893–4; also that of Mr. Paker, *Trans. Institution of Engineers and Shipbuilders in Scotland*, 1881–2.

If heated above a bright yellow, it may become crystalline, and suffer both in strength and ductility, but only if the cooling from that temperature is protracted. The heart of a slowly cooled ingot, for instance, is coarsely crystalline from this cause. Crystalline structure, as induced by slow cooling from a high temperature, may be dissipated, and the mechanical qualities of the steel perfectly restored, by raising the part to a bright yellow, cooling it quickly to a bright red (to prevent re-crystallization), and then allowing it to cool slowly, to anneal it and avoid hardness and internal stress.

Art. 566. Mild steel may be produced by two distinct processes: the **open-hearth** or **Siemen's-Martin**, and the Bessemer; for ship material, however, only the former is employed in this country. The raw material is *hematite* pig iron; this is pure iron with about 3·3 per cent. of *carbon*, and the same quantity of other impurities, namely, about 2 per cent. of *silicon*, 1 per cent. of *manganese*, a very little *sulphur* and *phosphorus*, and traces of *copper*. Now, mild steel is pure iron with about 0·2 per cent. of carbon, and 0·5 per cent. of manganese, and, accordingly, all that is really required to convert pig iron into steel is to deprive it of nearly all of its carbon, half of its manganese, and all of its other impurities. Open-hearth steel was first successfully made by M. Martin, by melting pig iron and scrap in a Siemen's regenerative furnace, hence the term "Siemen's-Martin."

The procedure usually adopted in this country is as follows: firstly, hematite pig iron and scrap steel are placed in the furnace and heated until they are melted. The manganese, silicon, and carbon are then extracted by throwing in hematite iron ore; this is a pure oxide of iron, and the immediate result of its addition is the evolution of much heat, due to the oxide of the ore combining violently with the manganese, silicon, and carbon of the pig, the "bath" of molten metal boiling energetically, due to the sudden formation and combustion of gas within it. The result of the combination of the oxygen and carbon is a gas, that of the silicon and manganese is the well-known waste product *slag*, which, having absorbed a considerable proportion of iron, floats molten on the surface of the fluid steel, where it serves the useful purpose of protecting it from the oxidizing and cooling effect of the air. In steel works there is always a large quantity of shearings from plates and bars, and of scrap returned from the various shipyards, and this material is utilized by melting some down with each charge. A furnace of ordinary capacity makes a charge of about 25 tons of steel, the operation lasting about 8 hours. The first half of the time is occupied in melting the pig and scrap, and the next in purifying it by the addition of ore, this being added gradually, so that the resulting incandescent gases may keep the steel in a constant state of ebullition and intense heat.

The oxygen of the ore does not combine with the carbon of the pig until it has carried away all the manganese and silicon, after which, by regulating the supply of ore, the precise quantity of carbon left in the steel may be adjusted with great nicety. It is important not to "burn out" all the carbon, otherwise the oxygen of the ore would begin to combine with the, now, pure iron, and owing to the fact that the resulting product, **oxide of iron** (burned iron), would remain interspersed throughout the metal, the mechanical qualities of the finished steel would be seriously prejudiced. Steel which contains oxide of iron is unreliable, and crumbles when worked at a white heat. Most of the shortcomings of the earlier mild steel (especially the Bessemer) were due to the presence of this injurious compound. The impurities **sulphur and phosphorus** are very injurious; steel or iron containing quite a small quantity of sulphur is

"red-short," *i.e.* it breaks almost carrot-like at a red heat. Phosphorus causes "cold shortness," *i.e.* brittleness when cold. By the ordinary process of steel manufacture neither sulphur nor phosphorus are eliminated, all that is contained in the raw material is found in the finished steel, and it is because hematite pig iron is very free from these two elements that it is chosen as the raw material (Art. 568).

When it is judged, by the appearance of the bath of molten steel, that all the manganese and silicon, and sufficient of the carbon have been burned out, a small sample is withdrawn, cooled, and hammered into a flat button, and the percentage of carbon ascertained, in a few minutes, by a simple, chemical, colour test. If too high, more ore is added, and other tests made until it is found right, whereupon the steel is tapped from the furnace into a large casting ladle. It has just been seen that all the manganese combines with the oxygen of the ore and enters the slag, and as about 0·5 per cent. is required in the finished metal, this has now to be added. This is usually done by throwing it (in the form of *ferro-manganese*) into the casting ladle, at the same time as the steel is poured in from the furnace; if thrown previously into the furnace much of it would be lost in the slag. Manganese is useful in that it neutralizes the bad effects of phosphorus and sulphur, and also because, having a great affinity for oxygen, it decomposes any oxide of iron which may have formed in the steel, carrying the oxygen into the slag. It is also useful in that it strengthens the steel, but does not, like carbon, cause a loss of ductility when quenched in water (Art. 559).

It was Siemen's invention of the **regenerative furnace** that made possible the manufacture of steel by the open-hearth process. The furnace proper is a low brick chamber, about 20 feet long by 10 broad, having a shelving floor or "hearth" to contain a pool or "bath" of steel about 18 inches deep. There are doors in the side to admit the raw material, the molten steel being withdrawn, by a plug hole and spout, into a large casting ladle. At both ends there are two openings, one above the other, having separate flues. Through one of these, at one end, hot air is admitted, and through the other, at the same end, hot coal gas; on entering the furnace they mingle and burst into flame, which, owing to their already heated condition, is intensely hot. The flaming gases pass to the other end of the furnace and escape indiscriminately through both of the openings there provided, heating on their way every part of the furnace and melting the pig and scrap lying on the hearth. When they leave the furnace they are still intensely hot, and, on their way to the chimney, heat white-hot the brickwork of the flues. Now, the regenerative principle consists in utilizing the heat of the flues to warm the ingoing gas and air, and this is done very simply, by merely reversing, from time to time (about every half-hour), the direction of the ingoing and outgoing currents, so that the former (air and gas, unmixed) may pass through the two flues recently made white-hot by the latter, and, by robbing the brickwork of its heat, itself become intensely hot. It is important that the outgoing current of incandescent gas shall deliver up all its heat to the brickwork of the flues, and for this purpose, therefore, each of the four flues are widened out into a large chamber—"regenerative chamber"—filled with open brickwork. The gas used in these and similar furnaces is termed "producer gas," and is made by the heating and incomplete combustion (aided by steam and air injection) of inferior coal; and it is conveyed under slight pressure through large pipes to the furnace. The quantity of air and gas admitted, and the direction of the currents, is regulated by suitable valves, so that the nature of the flame and the

intensity of the heat may be adjusted with great nicety. Furnaces on this principle are now sometimes employed in shipyards for heating the frame bars, etc.

Art. 567. The **Bessemer process** is, in principle, the same as the open-hearth one just described, but with an important difference in the manner of securing the purification of the molten pig. Here the steel is made in a large globular vessel (of plating lined with fire brick) termed a "converter." The procedure is roughly as follows: in the first place, molten pig iron is poured into the converter; next, oxygen is introduced to burn out the manganese, silicon, and carbon, but instead of throwing it in in the form of ore, as in the open-hearth process, it is injected in the form of atmospheric air, through small holes provided in the bottom of the converter. As the air rises through the molten pig it becomes decomposed into its two constituent gases, oxygen and nitrogen, the former of which at once combines energetically with the manganese, silicon, and carbon, giving rise to heat so intense that the comparatively cool pig attains, in about 12 minutes, an enormously high temperature.[1] Having burned out the manganese, silicon, and carbon, ferro-manganese—which contains both manganese and carbon—is added, and the steel withdrawn by tipping the converter, for which purpose it is swung on trunnions.

A serious **disadvantage of the Bessemer process** is the difficulty of ascertaining at what precise moment the carbon is all burned off, for as the steel within the converter is not open to inspection, its condition can only be ascertained by observing the changes in the nature and colour of the flame issuing from the neck of the converter (the spectroscope is employed for this purpose); it follows, therefore, that there is a considerable likelihood of the process of oxidation—*i.e.* decarbonization—being carried too far, with consequent burning of the steel; or of its not being carried far enough, with a consequent excess of carbon, and hardness in the steel. The presence of burned iron may, of course, be corrected by the final addition of the ferro-manganese, but as the manganese combines with the oxide and enters the slag, there may be too little of it left in the steel, or too much carbon. With the open-hearth process, on the other hand, the steel takes several hours to make, so that there is ample time to test it, and "cook" it, until it is precisely of the required composition. With the Bessemer process, there is no time for testing and cooking, for the liquid pig is converted into steel in about 12 minutes, whereupon the only source of heat, the air blast, must be shut off, else the steel would burn, and when it is shut off the steel must be tapped without delay, otherwise it would cool before it could be conveyed to, and run into the ingot moulds. Bessemer steel is used in enormous quantities for rails and heavy sections, but as the composition of each charge may vary considerably, it is not suitable for plates and bars, the mechanical qualities of which are specified within narrow limits and must satisfy stringent tests.

Art. 568. It has been observed that **the impurity phosphorus** cannot be eliminated by the ordinary process of steel manufacture. To do this an alkali, such as lime, which has a strong affinity for phosphorus, must be introduced into the furnace, and as the furnace lining is largely composed of acid silicate, the lime would attack it and soon cause its disappearance. When, therefore, it is particularly required to deal with

[1] An interesting description of the Bessemer process will be found in Bessemer's paper, *Trans. Institution of Civil Engineers*, 1859, or in another of his read before the *American Society of Mechanical Engineers* in 1896 (see *Engineering*, December 11, 1896).

the phosphorus (as when a large quantity is contained in the raw pig), a furnace or converter having an *alkaline* instead of an *acid lining* must be employed, in which case the resulting steel is termed "basic" steel, in contradistinction to the "acid" steel made by the ordinary process. The main advantage of the **basic process** is that it allows common pig iron to be used, for as this is highly phosphoric, it cannot be employed with the acid process. Although largely adopted on the Continent and in America, it is, as yet, comparatively little employed in this country for ship material; as regards the mechanical qualities of the resulting steel, there is little to choose between it and the acid process.[1]

Art. 569. Returning now to the **manufacture of plates and bars**, the molten steel, having been tapped from the furnace into a large bucket or "ladle," running on rails, is transferred to the *ingot moulds* arranged in a pit between the rails. The *ingots* vary in size; those for plates are usually about 5 feet long by 20 inches square, those for bars may be much smaller. Having cooled sufficiently on the crust to bear transportation, they are placed in a re-heating furnace or "soaking pit," where they are allowed to remain until they have attained the same bright, yellow or white heat throughout, after which they are passed through the "cogging mill." This is a pair of large rolls, one directly above the other, driven by a reversing engine of great power and speed. The upper roll may be raised or lowered, and as the ingot is passed backwards and forwards, it becomes longer and thinner, being, finally, a long slab about 9 inches thick and 20 inches wide. While still hot it is cut by hydraulic shears into short pieces termed "blooms" or "billets," each of a suitable size to form a plate, for which purpose the weight or mass of every plate ordered from the shipyard is calculated, so that, the sectional area of the slab being known, it is a simple matter to compute what length of it will contain the mass requisite to form any particular plate. It should be observed that the hot metal is moved about entirely by mechanical means, so that the men need hardly approach it.

The short slabs are now placed in a re-heating or "soaking" furnace, so that they may again attain a white heat, after which they are rolled into plates. The **plate rolls** are similar to the cogging ones just described, but they are longer, and there are two distinct pairs. The first pair, termed the "roughing" or "soft" rolls, reduces the soft slab until it is about twice the thickness of the required plate, and the second pair, the "finishing" or "hard" rolls, completes the operation. It is important to notice that while the rolling increases the length and reduces the thickness, it does not alter the breadth, *i.e.* the pressure of the rolls causes little or no *transverse* flow of the soft steel; consequently, the slab must be brought to the required breadth of the finished plate, by cross rolling, before its length exceeds that of the rolls (about 8 feet). When the plate leaves the roughing rolls, therefore, it is the same breadth as the finished plate, but about half as long and twice as thick. The finishing rolls differ from the roughing ones in that they are of chilled, cast iron, and have a hard, polished surface, the upper one being capable of minute vertical adjustment, so as to produce any required thickness of plate. As shown in Figs. 14 to 17, Plate 99, the thinning and elongating action of the rolls causes a longitudinal flow of the surface material of the slab, or plate, so that the ends of the finished plate are always more or less **laminated**; sufficient spare material must, therefore, be provided to permit of the entire removal of the imperfect ends. In the case of bars, the tendency of the rolling to produce laminations at the ends

[1] An interesting description of an extensive series of comparative tests of basic and acid steel will be found in Sir W. H. White's paper, *Trans. Institution of Naval Architects*, 1892.

is even more pronounced than in plates, owing to the greater drawing-out action. The breadth of a plate is, of course, limited to the length of the rolls (this being about 10 feet, as a maximum), its length, however, is practically unlimited. Towards the end of the rolling operation, the plate, as it cools, becomes covered with scale, which, if not removed, would be squeezed into it and cause a rough and imperfect surface. Its removal is effected during the rolling, by spraying water on the hot plate, or by rolling in switches of brushwood, for, as the latter pass between the rolls and are squeezed against the hot plate, they explode and cause the scale to fly off.

The finishing rolls should be of the same diameter throughout, otherwise the part of the plate rolled by the portion of large diameter would be longer than the remainder, and result in a **buckled plate** (Art. 537). It is a difficult thing to maintain the same diameter in the rolls, for, as the central part becomes hotter than the ends, it expands more than they, and produces a plate with wavy centre and flat margins. This effect is usually provided against by turning them rather smaller at the middle than at the ends, but until such rolls become hot in the middle, they tend, as before, to produce buckled plates; in these, however, the margins are wavy and the middle part flat. Thin plates may also become buckled when laid out to cool on the hot, iron floor of the steel works, due to the exposed edges cooling faster than the middle.

As the plates cool, they are lined off in conformity with the ordered dimensions, and are sheared forthwith to shape. The shearing machines employed for this work are of enormous size and power, some being capable of making, at one stroke, a cut 12 feet long through a $1\frac{1}{2}$-inch plate, and as the engine is stopped and restarted for each cut, the plate may be adjusted with great precision under the knife. When sheared to shape, the plates are carefully examined for defects, especially for laminations at the ends, and the ordered dimensions and various identification marks are painted and stamped on them.

The **manufacture of bars** requires different plant from that required for plates, and, consequently, some steel works confine themselves to making one or the other, bars or plates. Small ingots, about 12 inches square, are usually employed for bars. To transform one of these into an angle bar, it is passed through rollers provided with grooves, as shown in Fig. 6, Plate 99. In the case of a $3\frac{1}{2}$ by $3\frac{1}{2}$-inch angle bar, for instance, the ingot is first passed through three or four rectangular grooves, so that it may be reduced in size to about 4 inches square; in the next pass its rectangular section is changed into a sort of pointed crescent, and in the next into a very thick angle, each succeeding pass making it thinner and thinner. The finished bar is thus thick or thin according to the groove taken as the final one, but intermediate thicknesses may be obtained by a small vertical adjustment of the top roller. The finished bar may be several hundred feet long, and while still hot it is cut by a circular saw (sunk in the floor) into the ordered lengths. In order that a long bar may retain its heat during the numerous passes, and be still hot when cross cut, the rolls are made to revolve at a high speed. Bars of irregular section, such as bulb-tees, are awkward to make, for they must pass many times through the rolls before they assume their finished form; and their thickness cannot be so nicely or uniformly adjusted as with angle bars. For the manufacture of bars of various sections and sizes, a large number of rolls must be kept in stock, any particular set being fitted up in a mill as required; and as the changing of the rolls in this way involves considerable time and labour, it is usually delayed until a sufficient number of bars of this particular section is on order. This is one of the principal causes of the delays

which shipbuilders experience in securing delivery of small quantities of bars, especially when of unusual size or section.

Art. 570. Steel castings are made from practically the same material as plates and bars. To ensure ample fluidity, however, so that the steel may flow readily and fill every cavity of the mould, and also to minimize the formation of gas and the resulting defect of porousness, minute additions of silicon and manganese are usually made. It may be observed that ordinary steel bubbles and boils as it is poured into the ingot moulds, and this, of course, would be particularly objectionable when making a casting, for if the gas did not all escape before the steel solidified, it would cause porousness. In the first stage of its manufacture a plate is part of a massive casting (the ingot), and the principal difference between the material of a plate and that of a casting is due to the long-continued squeezing action of the rolls. Thus, while the steel of a large ingot may be crystalline, porous, or even flawed, the long-continued pressure and kneading effect of the rolling, as the mass is reduced at a white heat to a thin plate, is sufficient to produce perfectly dense, homogeneous metal, quite free from the defects of the ingot.

It is evident, therefore, that the **mechanical qualities of a casting** cannot be so uniform and perfect as those of a plate, and in practice, therefore, castings are not required to withstand such stringent tests. The tensile strength limits specified by Lloyd's rules, for instance, are 28 and 35 tons in place of 28 and 32, with an elongation of 8 per cent. in place of 20; further, in cold bend tests the pieces need only bend through 90 degrees in place of 180, the radius of knuckle being, as usual, one and a half times the thickness. Lloyd's rules require all important steel castings to be subjected to these mechanical tests, test pieces being cut either from the "head" or from projecting tongues of metal cast on for the purpose. The high standard of ductility required in plates is evidently not necessary in castings, for these are usually massive parts, in which rigidity is the quality most required; and, moreover, even though it may have 50 per cent. less ductility than a plate, cast steel is still very superior in this respect to the forged scrap iron for which it forms a substitute. It may be remarked that test pieces from castings often show no less ductility than do those from plates.

In the manufacture of castings there are three things to guard against: the existence of **internal stresses, contraction cavities or flaws** due to unequal shrinkage, and **porousness** due to occluded gases. The nature and effects of internal stresses are described in Art. 563, and, as there noticed, unless they cause flaws, they may be corrected by annealing, to which precautionary process all castings are subjected. Porousness may be due to unsuitability in the composition of the steel, insufficient fluidity, or badly designed "*vents*" and "*heads*" (by which gas escapes from the mould, and fluid steel enters to take its place), or the mould itself may be badly made or improperly disposed. In these matters, of course, special knowledge and experience are essential.

The **soundness of a casting**, as regards flaws and porosity, is tested, subsequently to the annealing, by "**drop**" and "**hammering**" **tests.** The former consists in raising the casting to a height of from 7 to 10 feet, according to its size, and letting it drop to the ground—the hardness of which should be that of a macadamized road. If at any place there is a serious flaw or defect, the resulting concussion is likely to discover it, by breaking the casting. Large stern-frames, cast in one piece, are not raised bodily, but are merely canted up to an angle of 45 degrees; and when there are projecting parts, such as the boss, cavities are made in the ground

to receive them, for if not the casting, though sound and good, might bend or break. In the case of slender, complex castings, the drop test is dispensed with, an additional tensile and bend test being taken. After the drop test the casting is suspended by chains and struck all over with a 7-lb. sledge hammer, so that by the clearness of the ring it may be judged whether or not the metal is intact and homogeneous throughout.

Castings often show **surface defects**, usually termed "blow holes;" and sometimes these are not confined to the surface, but enter tortuously into the mass. A small surface cavity may be filled up by electrically welding fresh metal into it (a serious defect cannot be satisfactorily corrected in this way); if its depth is uncertain, it should be ascertained by cutting into the casting; sometimes it may be proved large by observing how much water will disappear in it. Castings often warp out of line in the annealing furnace, in which case they are faired subsequently by local heating. According to the shape of the casting, a more or less complete wooden pattern is required; and unless the form is very irregular, this is usually made in the steel works (for here there is a well-equipped pattern shop, and better knowledge prevails as to the requirements) from a drawing, outline mould, sections, or offsets supplied from the shipyard. The rough casting is usually machined and finished in the steel works.

Art. 571. As noticed in Art. 258, **scrap forgings** are still extensively used in preference to steel castings. They may be made either from *scrap iron* or *scrap steel;* the former, however, is the more common. As regards efficiency and general reliability, there is little to choose between either material; forged scrap steel is somewhat stronger and more ductile than forged scrap iron, but as the weak points in a forging are usually the welds, and as steel does not weld any better than—if as well as—iron, its superior strength is here of little or no value. It should be observed that the mechanical qualities of forged scrap steel are very inferior to those of the scrap from which it is formed, for whereas the latter material is perfectly homogeneous, the former is not, the one being made by rolling down a homogeneous ingot, and the other by hammering numerous small pieces together at a welding temperature. In test experiments with forged steel and iron,[1] it was found that the tensile strength of the material of a well-hammered steel forging, made from ordinary 30-ton scrap, was only 23·8 tons, and the extension 19·5 per cent.; in the case of an iron forging, the strength was 20·6 tons, and the extension 14·9 per cent. It is evident, therefore, that much of the superiority of steel disappears when it is worked into a scrap forging. In many cases forgings are made from a mixture of scrap steel and scrap iron, chiefly because the latter is not always obtainable in sufficient quantities; and sometimes what is supposed to be scrap iron is really scrap steel. Such compounding of the two materials is objectionable, in that, should steel predominate at certain places and iron at others, the resulting irregular distribution of strong and comparatively weak material would reduce the efficiency of the whole under stress. If the two materials are thoroughly mixed, however, there appears to be little objection to their combination, *i.e.* for ordinary ship forgings. It may be observed that the shafting and other parts of an engine are very commonly made by hammering down, or forging to shape, a single large steel ingot; ship forgings, however, are practically always made from scrap.

In **making a forging**, the scrap is first cut into short lengths, which, after cleaning, are piled crosswise (on a slab of wood) into a little cube

[1] See a paper by the late William Denny, *Trans. Institution of Naval Architects*, 1880.

about 18 inches square, termed a "pile" or "ball." It is then placed in a furnace and raised to a white heat, in which condition the various pieces are sticky and plastic, and adhere to one another. This is then hammered, or "shingled," under a large steam hammer, being constantly turned about, so that the blows may compress the separate pieces into one compact mass; during the hammering the dirt or oxide which adheres to the scrap exudes in the form of molten slag. The hammering is continued until the mass is fairly cold, hard, and homogeneous, the resulting slab or "bloom" being then put aside for future incorporation in the forging. When a sufficient number of blooms are made, two are raised to a white heat and welded together; in so doing, however, they are not merely conjoined, but are squeezed into one another and struck on all sides, so that they may become a solid compact mass. More are added, and when a sufficient mass has accumulated it is drawn down to form part of the forging. On the extreme end of this (Fig. 5, Plate 99) a couple of fresh blooms are now placed, and, being heated together, they are welded as before, and the forging drawn out a little further. The resulting gradual formation or growth of the forging is shown in Fig. 5. A large mass is always retained at the end, to allow for the reducing action of the hammering.

Large ship forgings cannot be forged in one piece, for it would be impracticable to manipulate them under the steam hammer; they are, therefore, made in several parts, which are afterwards welded together. It is not unlikely that the **welds** will be **points of weakness**, and, in view of this, they are placed in positions where they will be the least exposed to stress, and at the same time be convenient for the forging and welding work. The usual disposition is shown in Figs. 1 and 2, Plate 40. In the case of a stern-frame Lloyd's rules do not allow a weld to be placed in the sole piece, for this part is liable to severe stress, through waves striking the rudder in heavy weather and through grounding. It should be observed that, if the welds are carefully and properly made, the forging should be as strong in way of them as elsewhere, but such perfection is not always attained.

As shown in Figs. 1 to 4, Plate 99, there are **four kinds of welds**: the *V weld*, the *glut*, the *scarph*, and the *jumped or butt weld*. For large forgings the V or the glut weld is employed. In making the former (Fig. 1), the two parts of the forging, having their ends cut to shape, are rigidly connected by bars, in such a way that, while clear of the joint, they hold the parts in their proper relative positions. A fire is then built around the joint, and when, after slow heating, a white heat is attained, the two parts are drawn forcibly together by previously attached chains and tightening screws, and are well hammered under a steam hammer, the longitudinal pressure of the screws and the lateral effect of the hammer blows producing a sound, close weld. With a glut weld (Fig. 2) the two parts are fixed together in the same way, but there are no tightening screws, and when heated white-hot, a triangular piece of iron—heated in another fire—is welded into the uppermost glut, this one being usually larger than the other; after this the forging is turned over, the joint re-heated, and another piece of iron welded into the other. As regards efficiency, there is little to choose between the two kinds of welds; the V weld is the favourite one in England, and the glut in Scotland. Scarph welds (Fig. 3) are suitable for keel bars and light parts, especially where the precise length after welding is unimportant. The jumped or butt weld (Fig. 4) is not so likely to be efficient, because of the small area of the welding surfaces, and the difficulty of applying end-on hammer blows. In light work, however, it is often the only one possible, but as here the end of the smaller part can usually be enlarged, palm-like,

it may be perfectly efficient; in such cases, however, it can hardly be classed as a butt weld.

Lloyd's rules make certain restrictions as to the **welding of forgings.** In the case of V welds they require the angle to be not greater than 60 degrees, for, in order to simplify the work, there is a natural tendency to make it obtuse, which, of course, if carried to excess, would result in a mere butt weld. Further, when the sectional area exceeds 40 square inches, the welds must be made by steam hammer; at one time only sledge hammers —and tightening screws—were employed, whose effect in the case of a large forging was necessarily superficial. The ends of the parts of a forging, about to be welded together, are left large and massive, so that the reducing effect of the hammer blows may not leave the forging of smaller scantlings here than elsewhere, and so that the welding temperature may be longer maintained. In repair work a broken forging is often repaired by welding a new piece to it, and in such cases a temporary increase of massiveness at the weld may be provided by staving up the broken end. A forging is not finished in every detail in the forge; it is only more or less accurately blocked out, and is afterwards finished in the smiths' shop, by local heating and chipping; after this it is machined where necessary, the rivet holes are drilled and the scarphs planed. There are thus three processes in the making of a finished forging: the forging, the smithing, and the machining; in many cases, however, the smithing is dispensed with, the forging being finished entirely by machine.

APPENDIX

Art. 572. Fig. 1, Plate 114, represents a beam of solid, rectangular section, with a load at the middle deflecting it downwards between the supports. In its bent condition the ends are no longer parallel, but conform with the converging radii of an arc, remaining square with the upper and lower surfaces. As these surfaces now form arcs of concentric circles,[1] the inner one must be shorter than the other, *i.e.* it must have compressed or the outer one must have stretched. In reality, both actions have occurred, the upper one has shortened and the lower one lengthened; the length of the beam at mid-depth, however, is unaltered, *i.e.* the material here has neither stretched nor compressed. The fact that compression and extension occur in a **deflected beam** is familiar; it is well shown by a piece of rubber, which, when bent, clearly shows compressive and tensile effects.

The condition of the material of a bent beam, as regards internal stresses, may be readily appreciated by considering the case of one composed of several superposed layers, unconnected, as shown in Fig. 2, Plate 114. When such a beam is bent, its ends do not become coincident with the radii of an arc, but remain parallel, the various layers slipping upon one another, so that their ends depart from the flush. To create in this beam (when so bent) the internal stresses which prevail in the solid one shown in Fig. 1, the four upper layers must be compressed endwise, say, by external forces, and the four lower ones elongated, all in such a way that their ends may become flush and correspond with the radii RR. If now, when so compressed and extended, the layers are united (say, glued together), they will remain in their compressed and extended states when the external endwise forces are removed, and evidently the beam will then be in the same condition as that shown in Fig. 1.

The external compressive force required to shorten No. 4, the uppermost layer, or the resistance or force of recovery offered by it to such compression (the two things are, of course, identical) is four times greater than that required to compress No. 1 layer (the magnitude of the forces is shown by the lengths of the small arrows), for it must be shortened four times as much, and, as is well known, the force necessary to compress or extend any substance—within its elastic limit—is proportionate to the amount by which it is compressed or extended; an ordinary spring balance is a familiar illustration of this. Further, the total compressive forces acting on the upper four layers must equal the total tensile forces acting on the lower four, otherwise, when they are removed (after uniting the layers), the beam would either shorten or lengthen as a whole; in other words, the effort of the compressed layers to lengthen must be met by a similar effort of the extended ones to shorten.

All beams, of whatever section, may be conceived to be composed of numerous, infinitely thin, horizontal layers. On the application of a

[1] A beam deflected by a load at the middle does not assume the curve of an arc of a circle, but the assumption is permissible, and simplifies matters.

deflecting load, the upper ones are compressed and the lower ones extended, and, as shown in Fig. 2 (Plate 114), the amount of compression or extension is proportional to the distance from the central one (or, more correctly, the distance from the neutral axis or centre of gravity of the sectional area). The layer at mid-depth of a beam of solid, rectangular section is neither compressed nor extended, it is therefore termed the "neutral layer" (Fig. 2). If observed in section, it appears as a horizontal line, termed the "neutral axis" (NA, Fig. 1). Whatever the section of a beam, the neutral axis passes through the centre of gravity of its sectional area;[1] in the case, therefore, of a solid, rectangular one, it is at mid-depth, but in those of unsymmetrical section, it may be quite off the centre, and the areas above and below may be quite unequal; the essential condition is *equality in the forces of compression and extension* brought about by the deflection of the beam. In a beam of solid, rectangular section the layers are all of the same breadth; in others they may vary in breadth, or may be absent in places. In the case of an **I**-section beam (see the section in Fig. 6) the layers composing the web are very narrow, they therefore give little strength compared with the broad layers forming the flanges; nevertheless, weight for weight, this is a most efficient type of beam, because a large proportion of the material is concentrated where it is most effective, remote from the neutral axis; a third flange at mid-depth would suffer no stress, and would, therefore, be unable to contribute any strength. A "lattice" beam may be described as an **I** beam, in which the upper and lower flanges are united by diagonal links instead of a solid web (Fig. 6). A web of this kind contributes no longitudinal strength to the beam; if the flanges were removed and the ends of the links pivoted together, it might be extended or shortened, as in the familiar contrivance known as "lazy tongs." Its function is to hold the flanges at fixed distance, and prevent relative longitudinal slipping movement; it conveys the compressive forces acting on the upper flange to the lower one, and, conversely, the tensile forces acting on the lower to the upper, so that the one set of forces may resist or balance the other. Weight for weight, a lattice beam or girder is the most efficient, for, as a minimum of material serves for the web, a maximum may be concentrated in the most effective positions—the upper and lower flanges. Of course, the diagonal disposition of the links is essential, for, were they parallel, the upper and lower flanges would be free to move endwise relatively to each other, as in a parallel ruler, and longitudinal stresses affecting the one could not be conveyed to, and be held in check by, the other. In Fig. 2, for instance, the layers composing the beam are free to slide endwise upon one another, and consequently they do not co-operate, *i.e.* each one acts independently as a shallow beam. As the strength of a beam varies as the square of its depth (Art. 573), the strength of each layer is here only $(\frac{1}{9})^2$ or $\frac{1}{81}$ that of a solid beam of the same depth; and as there are nine layers, their combined strength is only one-ninth of the strength of the solid beam shown in Fig. 1.

In Fig. 3 (Plate 114) the load on the beam, acting downwards, is balanced by a force at either end acting upwards, each of the latter being, of course, equal to half the weight of the former.[2] The load, in deflecting the beam, causes, as just seen, internal longitudinal stresses of compression and extension, but, although brought about by the load, these forces do

[1] Assuming the resistance of the material to be the same, both in compression and extension.

[2] In a beam carrying a concentrated load placed anywhere upon it, the support given at either of the two ends is that proportion of the load which the distance of the load from the *other* end bears to the total length of the beam.

not support it, for horizontal forces cannot balance vertical ones; they merely convey the upward pressures acting at the ends to where they are required—under the load.

The fact that equal horizontal forces, acting in opposite directions, parallel to each other, but not in the same line (as is the case with the compressive and tensile stresses in a beam), may transfer the effort of a vertical force from one point to another, is shown graphically by the contrivance illustrated in Fig. 7 (Plate 114). The double bell-crank lever L is free to move vertically in the standard S. It is loaded, over the fulcrum, with a weight of 1 lb., which is balanced by a similar weight, acting upwards, not below it, but at the end of the lever. If the lever is in equilibrium, then it must be the latter weight that balances the former, for the only other forces in operation are C and T, which, acting horizontally, have no disturbing effect on vertical forces. It may be readily shown that the lever is in equilibrium: firstly, as it is acted upon by an upward and a downward force of equal intensity (A and A^1), it cannot move, as a whole, vertically; secondly, as it is acted upon by a horizontal force to the right and an equal horizontal force to the left (C and T), it cannot move, as a whole, horizontally (the fulcrum is shown working in a horizontal slot, yet it does not move either way). The only other movement which might occur is one of rotation, but here again there is equilibrium; for while the two horizontal forces tend to cause rotation in the direction of the hands of a clock, the two vertical ones tend to produce the opposite movement; and the two contrary tendencies balance each other, because their "*moments*" are equal. The moment or turning effort of two equal forces acting in different parallel lines (known as a "couple") is obtained by multiplying either force by the distance between their lines of action. If the moments of the two sets of forces in the diagram are computed, it will be found that both are equal to 4; 4 lbs. multiplied by 1 foot for the horizontal forces, and 1 lb. multiplied by 4 feet for the vertical ones.

In Fig. 8 (Plate 114) a similar set of vertical and horizontal forces is shown acting on an **I**-section beam, in which the strength of the web is insignificant compared with that of the flange, and may, therefore, be neglected; or it may be regarded as a lattice beam, in which type the strength lies altogether in the two flanges. It will be observed that, to indicate the effect of compressive and tensile forces, the flanges are cut away at one point, and are made good by spiral springs; further, to facilitate the comparison with the former diagram, an imaginary bell-crank lever is drawn on the side of the beam. The forces in operation are indicated for one-half of the beam only, those affecting the other half are the same, excepting that the horizontal forces act in the opposite direction.

The tendency of force A (Fig. 8, Plate 114) to bend the end of the beam upwards (or, what is the same thing, the tendency of half the load, to bend the middle downwards) is measured by its moment, or "**bending moment,**" as it is termed, and the resistance of the material of the flanges, or springs, to such deflection is measured by their moment, termed the "**moment of resistance.**" The former forces are *external*, the latter *internal*. The bending moment of the external forces at any point in the length of a beam must equal the moment of resistance of the material at the same point; that is to say, when there is equilibrium, the tendency of the external forces to bend the beam must be met by an equal resistance on the part of the material of the beam itself to such bending. Thus, the bending moment of force A, taken about the centre of the beam, is itself multiplied by half the length of the beam; and the moment of resistance of the material of the flanges, or springs, at the same point, is either of

the equal forces C or T, multiplied by the depth of the beam (or, if the forces are unequal, the sum of each one multiplied by its distance from the neutral axis); and, as just seen, these two moments must be equal, for if not the beam will deflect until they are. If the load be doubled, for instance, then not only will the upward pressure at each support be doubled, but the beam will deflect twice as much as formerly, so as to cause the material of the flanges, or springs, to stretch twice as far, and thus yield a double resistance. The bending moment at point Q, situated quarter of the length of the beam from its end, is only half what it is at the middle, for it is the same force, A, multiplied by quarter, instead of half the length of the beam; it follows, therefore, that the moment of resistance of the material at this point must also be half what it is at the middle, consequently the flanges—or springs, if placed here—must, of necessity, only be half as much compressed or extended at this point, for they act with the same leverage, namely, the depth of the beam; that is to say, the stress on the material of a beam of uniform depth, loaded at the middle, is only half as great at a point one-quarter of its length from the end as it is at the middle, and similarly for other points. The maximum bending moment or tendency of the beam to break is, therefore, situated at the middle, under the load; thence towards the ends it diminishes, becoming zero over the supports. With a given load, the maximum bending moment occurs when it is concentrated at the middle. When distributed throughout the length, the bending moments and internal stresses are more uniform, the maximum are still at mid-length (assuming the ends of the beam to be free), but they are only half as great as when the load is concentrated here. For instance, a beam which could only support a ton weight at the centre might support two if uniformly distributed.

Art. 573. The strength of a beam varies inversely as its length. If the length be doubled, for instance, then, as the distance between the load (concentrated, say, at the middle) and the supports is doubled, the maximum bending moment, and the corresponding stress on the material of the beam, are also doubled; that is to say, the same load, when placed on a beam of double length, causes double the stress on the material; and, consequently, such a beam can only support half the maximum load of the shorter one, *i.e.* the strength of a beam diminishes in proportion as its length is increased (see Figs. 12 and 13, Plate 114).

The strength of a beam varies directly as its breadth. This is obvious; in the case, for instance, of a beam of solid, rectangular section, to double its breadth is equivalent to placing another alongside of it, the two together having, of course, twice the strength of one. Similarly, in beams of odd section, if the horizontal dimensions of all parts be doubled, so will the strength be doubled. In beams having slender flanges connected by a web, an undue increase in the breadth of the former might, of course, reduce the efficiency of the beam, for the marginal parts of the flanges, where remote from the stiffening effect of the web, would shirk severe compressive stresses by bending or buckling. Accordingly, when the flanges of a beam exceed a certain moderate breadth (Fig. 9A, Plate 13), they must be stiffened against lateral deformation. This may be done by introducing an additional web, making the beam of box section, as shown in Fig. 9C, or the flange may be stiffened and supported, as shown in Fig. 9B; the broad flanges commonly adopted in bridge girders are usually supported, and the web stiffened by fitting angle or tee bars at intervals, as shown in Fig. 9B.

Notice, now, **how the strength of a beam is affected by**

variations in its depth. First consider the case of the beam or girder, shown in Fig. 8, Plate 114, and assume it to be of lattice type. If the depth be, say, doubled, then, as both springs would act with double their former leverage, they would have double the moment of resistance, and the beam could support double the load. In a beam, therefore, whose strength all lies in the upper and lower flanges, the strength varies simply *as the depth.* In a beam of solid, rectangular section, the numerous layers throughout its depth might be similarly represented by a series of springs, and it is evident that if the depth of such a beam be, say, doubled, not only would each of the original springs or layers (imagine them to be set twice as far apart, so that they may occupy the same relative positions) have double the effect due to their double leverage, but, with the additional intermediate ones, there would be twice as many; consequently, the strength would first be doubled by reason of the double leverage, and then again doubled because of the double number of springs or layers. The moment of resistance of the material of the beam would, therefore, be four times greater; that is to say, the strength of a beam of solid rectangular section varies as the *square of its depth.* It should be observed that, while the *strength* of a lattice beam increases simply as the depth, its *weight* (neglecting that of the links) remains the same, whereas in the case of a solid rectangular beam the weight increases with the depth. In the case of a beam of irregular section, such as an **I** beam, an increase in the depth affects differently the different parts; thus, while the material of the flanges gains strength in simple proportion to the increase in depth (as in the lattice girder), that of the web gains strength in proportion to the square of the depth, for it is really, in itself, a slender beam of solid, rectangular section. It follows, therefore, that the increase in strength due to an increase in the depth of such beams lies somewhere between the first and second power of their depth.

Notice, now, what governs the **position of the neutral axis,** and how again its position affects the efficiency of a beam. As already seen, the neutral axis corresponds in position with that layer which suffers neither compression nor extension. In Fig. 8, Plate 114, the compressive stress, or push, of the upper spring is equal to the pull of the lower one, for they are strained or stretched by the same amount; it follows, therefore, that the pivot of the imaginary lever is pushed to the right just as much as it is pulled to the left, and consequently it is on the neutral axis—it does not move, though placed in a horizontal slot. If, now, an additional spring be placed alongside of the upper one, or, what is the same thing, if the sectional area of the top flange be doubled (Fig. 9), then it is evident that the compressive stress, or push, exerted by the pair will be twice as great as the pull exerted by the lower one, and consequently the pivot of the imaginary lever, if still at mid-depth, will be pushed to the right by the force of the additional spring. It is, therefore, no longer on the neutral axis; this now lies at one-third of the depth of the top, for if the pivot be placed here, as shown in Fig. 9, then the compression of the *two* upper springs will only be half as great as the extension of the lower *one* (shown in relative magnitude by the distances c and t respectively), consequently, they will exert the same total force as the latter, and the pivot will again be in equilibrium, *i.e.* it will again be on the neutral axis, the horizontal forces C and T being still equal. The two upper springs may be taken to represent an upper flange, having 2 for its sectional area, and the lower spring a flange, having unity for its sectional area; the centre of gravity of the two flanges (or neutral axis of the lattice beam) is, therefore, situated at one-third of the depth from the upper one, for the statical

moment of the former about this point is equal to that of the latter, this equality being the condition governing the position of the centre of gravity.

It follows from the above that that beam is the most efficient in which the neutral axis is at mid-depth, for, when subjected to a deflecting force, the material above and below it, being strained by the same amount, will contribute equal resistance. If, for instance, the lower flange suffered twice the stress (per square inch) of the upper one (which, as just seen, is the case when the neutral axis is at one-third the depth from the top), its failure, under an excessive load, would occur long before the upper flange experienced any severe stress, or, in other words, before it had an opportunity of exerting its full power of resistance. In Fig. 9 (Plate 114) the extension of the single lower spring is twice as great as the compression of the two upper ones, it is, therefore, doing an unfair share of the work; the latter are quite as capable, but as they are twice as near the neutral axis, they cannot at any time exert more than half the power of the lower one.

Art. 574. In the foregoing, attention is directed to those matters which govern the strength of beams, and it is now intended to notice those which govern their readiness or otherwise, to yield or deflect under a load, or, in other words, their elasticity or stiffness. As noticed in Art. 23, stiffness is a quality quite distinct from strength. The **stiffness of a beam is measured by its deflection.** A deflected beam assumes a certain *curvature*, whose radius is large or small, according as the *deflection from the straight* is small or large. The deflection is proportionate to the curvature, *i.e.* it is inversely proportionate to the radius of curvature. This may be shown to be the case by geometrical construction: thus, in Fig. 10, Plate 114, the large circle is drawn with twice the radius of the smaller, and if the small arcs between the points AB and *ab* in the circumferences be taken as representing two beams of equal length, it will be found that the deflection of the one in the small circle (2 D) is twice that of the other (D), as also, by construction, is its curvature; that is to say, deflection and curvature vary together, the one measuring the other. It will be found that the above is only true for small curvatures, such as occur in beams bent within the elastic limit.

It will now be a simple matter to show that the **deflection of a beam varies as the load.** It has already been observed that the compression or extension of the material of a beam varies with the load; if this be doubled, so will the stress, resistance, or strain of the various layers (or the springs in Fig. 8, Plate 114) be doubled (Art. 572); and, further, when the amount of the longitudinal compression or extension of, say, the upper and lower layers is known, so is that of all the other layers; if, for instance, the compression and extension of the upper and lower layers be doubled, so will that of all the intermediate layers be doubled, and all will give a double resistance. In Fig. 2, for instance, double the load will cause a double amount of slip in all the layers, so that double the force will be required to compress or extend them. In a beam deflected by different loads, therefore, the comparative longitudinal resistance offered by the layers may be measured by noting the amount of compression or extension of the upper and lower ones, *i.e.* by observing how much the upper or lower surface of the beam has shortened or lengthened. Now, as just seen, if the load be doubled so will the compression and extension of the upper and lower layers be doubled, and it will now be shown that the latter effect implies a double degree of curvature. In Fig. 11 (Plate 114) a 6-inch bar of some flexible material is shown bent to a complete circle, and it is evident that, as the diameter of its outer surface is 1 foot greater than that of its inner one, its length must be 3 feet greater (or, more accurately, 3·141). The upper (or inner) layer must, therefore, have

compressed 18 inches, and the lower (or outer) one extended 18 inches. If, now, the *same* bar is bent with a smaller curvature, say, to that of a circle of twice the former radius, then, as shown in Fig. 11, it will only be long enough to make half a circle, and the difference in the length of its upper and lower surfaces will only be half as great as formerly, for the length of a semicircle is one and a half times the diameter, instead of three times, as in a complete circle, consequently the compression and extension of the material of the upper and lower surfaces will only be half as great, or 9 inches instead of 18; that is to say, the load or force necessary to bend the bar to the easier curve of the larger circle will only be half as great. The curvature of a beam, therefore, varies with the load, and as it has just been shown that the deflection varies as the curvature, it also must vary with the load; if the load be doubled, so also will the deflection.

The **deflection of a beam varies as the cube of its length**; if its length be doubled, for instance, it will deflect eight times as far under the same load. That this is so may be shown as follows. The beam in Fig. 13, Plate 114, is twice as long as the similar one in Fig. 12, it is, therefore, only half as strong, and, accordingly, the single weight at its centre will cause the same internal stresses as the two weights on the other, for as the external bending moments are the same in both beams, so must be the internal moments of resistance. The two beams must, therefore, have the same curvature, for their layers must, to give the same resistance, be compressed and extended by the same amount per foot of length, *i.e.* they form arcs of identical circles, or, more correctly, their curvature is identical. If, now, recourse is again had to geometrical construction, it will be found, when the deflection is small, that that given by an arc twice the length of another (as BB and *bb*, Fig. 14) is four times greater, *i.e.* it varies as the square of the length. In two similar beams, therefore, loaded to such an extent as to subject them to the same internal stresses, the deflection varies as the square of the length. Observe that the load is here inversely proportionate to the length. If, now, the load on the long beam (Fig. 13) be doubled, so as to make it equal to that on the short one (Fig. 12), the deflection also will be doubled, so that instead of being only four times greater than that of the short beam, it will be eight times greater; that is to say, with the same load, the deflection of a beam varies as the cube of its length.

Consider, now, **how the stiffness or deflection of a beam is affected by variations in its depth.** In the first place, notice the case of two lattice girders, one, say, 1 foot deep, and the other 2 feet. As already noticed, the strength of the latter is twice that of the former, for the material of the flanges (the only effective material) acts at double the leverage from the neutral axis. If, now, both girders are bent to the same curve, the difference in the lengths of the two flanges—which represents the stress on the material—will evidently be twice as great in the deep one. To so bend it, therefore, would require four times the load, for its material not only acts at double leverage, but is strained by a double amount. And if the load upon it were the same as that on the other, then, of course, the deflection would be only one-quarter as great; that is to say, **the deflection of a lattice girder varies inversely as the square of its depth.** A beam of solid, rectangular section may be regarded as made up of numerous lattice girders, of diminishing depth, placed one within the other. If, now, such a beam be doubled in depth, not only will every one of the imaginary lattice girders composing it become (as just seen) four times as stiff, but there will be twice as many of them, which circumstance will again double the total stiffness, making it eight times greater than originally; that is to say, **in a beam of solid, rectangular section,**

the deflection varies inversely as the cube of the depth. In beams of irregular section, such as **I**, bulb-tee, or angle beams, the variation in stiffness due to variations in depth lies somewhere between the second and third power, for while the stiffness due to the greater distance of the flanges or bulb from the neutral axis varies as the square (as just shown for a lattice girder), that due to the increase in depth and sectional area of the web varies as the cube. It was noticed in Art. 573 that the increase in *strength* of such beams lay between the first and second power of their depth.

Art. 575. The manner in which the ends of a beam are supported has an important influence on its strength and stiffness. In the foregoing it is assumed that the ends merely rest upon the supports, so that they are free to conform with the general sag or curvature of the beam. If, now, they are rigidly held, the conditions will be greatly altered. Fig. 4, Plate 114, shows the kind of curve that **a beam with fixed ends** assumes on deflection; while the middle half takes the curvature of a beam with free ends, the two end quarters take a reverse curvature, convex on the top. Comparing the beams in Figs. 3 and 4, the one with fixed ends is *twice as strong, i.e.* the same *concentrated load* will only cause half the stress on the material. As regards stiffness, a still greater increase results from the fixing of the ends, for, with the same concentrated load, the *deflection is only one-quarter as great.* Notice that, *when the load is distributed*, the strength is only about *one and a half times as great*, and the deflection *one-fifth as great.*

The **increase in strength and stiffness due to fixing the ends** may be explained by considering the case illustrated in Fig. 5, Plate 114, which represents the beam in Fig. 4 cut into three parts (at the points QQ, where it is cut, one-quarter the length from the ends, there are no internal longitudinal stresses, and consequently the cutting does not affect the conditions prevailing in the three parts). Firstly, as regards the strength and stiffness of the middle part, it is evident that as this is half the length of the similar beam in Fig. 3, it is twice as strong, and will deflect only one-eighth as much. As regards the two end quarters, the external bending forces and internal stresses prevailing in each one are identical with those prevailing in each *half* of the middle part, and as all four parts are of the same length, their strength, stiffness, and deflection under stress are the same (the two end quarters, if combined, as shown by the dotted lines, form a beam identical with the middle half). It follows, therefore, that the strength of the combination (Fig. 5), or of the intact beam (Fig. 4), may be measured by that of the middle half, *i.e.* it is twice that of a full-length beam having free ends. And the deflection is only one-quarter as great, for it is equal to that of the middle part, plus that of either end portion, which are each equal to one-eighth that of a full-length beam having free ends. A beam with fixed ends suffers, when *uniformly* loaded, double the stress at the ends that it does at the middle, and, consequently, if loaded to destruction, it would break at either or both ends. With a concentrated load, the stress at the ends and at the middle is the same, consequently the beam is as likely to break at the one place as at the other. It is important to note that, in ship construction, practically all parts are in the condition of a beam with fixed ends, and in most cases the load or bending pressure is uniformly distributed.

Art. 576. The upward pressure exerted by the water surrounding **a floating body** must, of necessity, equal the weight of such body, and it may easily be realized that either of these two things is equal to the weight

of the water displaced by the body. In the case of a ship, for instance, imagine the hull to be cut off flush with the water-line, the upper deck to be relaid at this level, and all the above-water parts stowed in the hold; the operation would not affect the ship's flotation, excepting, of course, that, having no *spare buoyance*, she would remain motionless, either at or below the surface. To show, now, that the weight of this hull is equal to its displacement, *i.e.* to the weight of a volume of water of the same outward form, imagine a hull of the same shape consisting solely of an infinitely thin shell filled with water; then it is evident that, being merely a mass of water, it also would remain motionless wherever placed, at or below the surface. As regards weight, therefore, it and the original hull are evidently identical; that is to say, the weight of a floating vessel is equal to the weight of the volume of water displaced.

Art. 577. Brass varies greatly in its composition; ordinarily it contains 2 of copper to 1 of zinc. Its tensile strength is about 11 tons per square inch; it is soft, and has little ductility.

Gunmetal, or bronze, differs from brass, in that it contains tin instead of zinc. Its composition varies, but it usually contains about 90 per cent. of copper to 10 of tin; that used by the Admiralty contains 88 per cent. of copper, 8 of tin, and 4 of zinc. It is hard and tough, its tensile strength being about 17 tons per square inch. It is the best material for small valves and castings where great toughness and strength are required. As the price of zinc, copper, and tin is roughly in the proportion of 1, $2\frac{1}{2}$, and 5, it is evident that gunmetal is a more expensive material than brass, but it is also a very superior one.

Yellow metal or Muntz metal contains about 3 of copper to 2 of zinc. It is very malleable, and has a tensile strength of about 22 tons per square inch. It has, however, the serious disqualification of changing its nature in sea water, the zinc separating from the copper.

Naval brass is Muntz metal with 1 per cent. of tin, this addition removing the tendency to deteriorate in sea water, while not affecting the strength or ductility. It is largely used for the bolting of under-water valves, and of the wood planking of sheathed and composite vessels.

Phosphor-bronze, such as is used for the stems, stern-frames, rudders, and shaft brackets of sheathed warships, contains 90 per cent. of copper and 10 per cent. of phosphor-tin, the latter containing 5 per cent. of phosphorus. It is very hard and tough, and has a tensile strength of about $15\frac{1}{2}$ tons per square inch.

Nickel steel is an alloy of ordinary mild steel and nickel.[1] Its properties vary according to the proportion of nickel. The addition of this element greatly increases the strength and toughness of the steel, and, in some grades, has the important effect of raising very largely the ratio of the elastic limit to the breaking strength. Steel containing rather less than 5 per cent. of nickel has a tensile strength of about 40 tons, an elastic limit of 28, and an elongation in 8 inches of about 15 per cent.[2] As ordinary mild steel has a tensile strength of about 30 tons and an elastic limit of 16, the elastic limit of the above alloy is practically equal to the ultimate strength of ordinary mild steel, a most important advantage in

[1] Information on the subject of nickel steel will be found in a paper by Mr. James Riley, read before the *Iron and Steel Institute* in 1889, and another by Mr. Henry A. Wiggin, read before the same Institute in 1895; also in papers by Mr. William Beardmore, read before the *Institution of Engineers and Shipbuilders in Scotland* in 1896, and before the *Institution of Naval Architects* in 1897.

[2] Riley.

the material of a structure liable to intense stresses of uncertain magnitude. Another important quality possessed by nickel steel is its ability to withstand shock; when subjected to intense concussion, a bar or plate of ordinary mild steel, although soft and ductile under ordinary tests, may crack, showing a crystalline fracture, just as if it were brittle. Nickel steel does not so readily crack, and a crack, if started, does not run across as with ordinary steel; and, further, if a bar is nicked and broken, the fracture is fibrous; with ordinary mild steel it is usually crystalline, the bar breaking short off, as if it were brittle. It may be welded as readily as ordinary steel, and it loses no more strength by the action of the punch. It is rather more difficult to machine, and this characteristic increases with the percentage of nickel; a 25 per cent. alloy is so tough that it is almost impossible to drill a hole in it, nevertheless it may be punched with ease, and is so ductile that it may be drawn into fine wire. It does not corrode so readily as ordinary steel, the rate of corrosion, in the case of a 5 per cent. alloy, being only about half as great.

The great strength and high elastic limit of nickel steel makes it eminently suitable for structural purposes where lightness and strength are desired, because, with the same weight of material, greater strength and reliability may be secured, or, with a smaller weight, the strength may be undiminished. As its cost is much greater than that of ordinary mild steel, it has not as yet been used for ordinary shipbuilding; the reduction in the weight of hull that might follow from its adoption, and the consequent increase in the vessel's efficiency, being too small to warrant the greater first outlay. For armour plates and guns, its great toughness has secured for it a leading place; for torpedo boats, where strength and lightness are most essential qualities, it may be used with advantage; but, as noticed in Art. 552, ordinary carbon steel, of high tensile strength, is the material generally used for these light-scantlinged vessels, for, in strength and ductility, it is practically all that can be desired.

Art. 578. Owing to the irregular form of a vessel's hull, different methods are in vogue of measuring the three **dimensions of length, breadth, and depth.** The following briefly describes the different measurements.

Length over all is measured between the forward and after extremities of the hull.

Length between perpendiculars is measured from the forward part of the stem to the after part of the rudder post. If the stem or post are raked, the length is measured between perpendicular lines struck through the intersection of the upper deck (or second deck, in the case of shelter or awning-deck vessels) with the front of the stem and back of the rudder post. If the stem is bent to form a cutwater, the front of the straight middle part is extended up to intersect the deck.

Length registered is the same as the length between perpendiculars.

Length by Lloyd's rules is the length between perpendiculars, measured, however, to the inside of the stem and rudder post.

Length on load water-line is measured from the front of the stem to the back of the rudder post at the level of the load water-line.

Depth moulded is measured amidships from the top of the keel (or intersection of the outside of the frame with the centre line) to the level of the top of the upper-deck beam at the gunwale (or of the second deck in the case of shelter or awning-deck vessels).

Depth by Lloyd's rules is the depth moulded, plus the camber of the

deck beam, assuming this to be equal to $\frac{1}{4}$ inch for each foot in the length of the beam.

Depth registered is the depth amidships from the top of the double bottom, or from the top of the floors if there is no double bottom amidships, or from a point $2\frac{1}{2}$ inches above these points where ceiling planking is fitted amidships (whatever its thickness), to the top of the upper-deck beam (or second deck in the case of shelter or awning-deck vessels).

Breadth moulded is the greatest breadth of the hull, measured to the outer surface of the frames.

Breadth registered is the extreme breadth to the outside of the shell plating.

A vessel's *gross tonnage* is her internal volume (measured in a certain prescribed way) in units of 100 cubic feet. Her *under-deck tonnage* is the gross tonnage less spaces situated above the second deck from below. Her *nett or register tonnage* is the gross tonnage with certain deductions on account of the space occupied by the propelling machinery, crew, etc. For detailed information on tonnage laws and tonnage measurement the reader is referred to Sir W. H. White's " Manual of Naval Architecture."

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